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9 781882 580392
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17 Vacuum Tube Designs

FIRST EDITION
Audio Amateur Press
Publishers
Peterborough, New Hampshire

FIRST EDITION
2002
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Distribution Agent:
Old Colony Sound Lab
Post Office Box 876
Peterborough, New Hampshire 03458-0876 USA

ISBN 1-882580-39-7

First Printing April 2002

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Introduction

A Tube Cornucopia

This special collection of prime article projects is a clear testimony to the continuing enthusiasm, worldwide, for vacuum tube technology. The majority of those whose work is included here live outside the United States. It is now 14 years since this company launched *Glass Audio*, a periodical for tube lovers with a penchant for building their own equipment.

Despite the difficulties of dwindling supplies of tubes, rising prices on many of them, and the very slow development of other manufacturing sources in Eastern Europe, Russia, and China, the community of enthusiastic tube project constructors seems to grow steadily.

In 2001 we combined the *Glass Audio* title into a new magazine, *audioXpress*, with materials from our other publications, giving special attention to topics covering solid-state equipment and loudspeakers. At that time many were sure that the interests of tube lovers would be neglected and that interest in tubes would suffer.

Quite the opposite has happened. In *audioXpress* speaker enthusiasts are discovering the wonderful world of tubes, and the solid-state people are seeing possibilities in hybrid circuits, which combine the advantages of solid-state power and voltage control serving the operation of tube circuitry in ways not possible in the earlier history of electronics.

Almost everything in the world of electronic components has changed in the 40 years or so since the beginning of a shift to solid-state topologies. Capacitors are infinitely better, and resistors are quieter, much more precise, and cheaper. Almost every ancillary part in tube designs is better and cheaper today than it was when tubes began to be regarded as obsolete. In short, tubes are sounding better than they ever did.

Tube enthusiasts also know that building tube equipment is, in many ways, easier and more fun than solid state. The feeling is much more "hands-on" with tubes. Wiring is simpler point-to-point, and the resulting units are easier to modify or repair.

It was with all these facts in mind that we made the decision to put together this really outstanding group of articles by world-class authors. Our thanks to them for their work, their passion, and their clever insights which have made all this material possible. *—The Publisher*

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COVER PHOTO: MICHAEL BURROWS

An SV300B Push-Pull Amplifier

This article was originally published in the November 2000 issue of Japan's premier high-end tube magazine, *MJ Audio Technology.*

By Satoru Kobayashi

[Since this article was written, the 300B is no longer available from Svetlana. It is available from Westrex (1230 Peachtree Street, #3750, Atlanta, GA 30309, 404-874-4400, Fax 404-874-4415, sales@westernelectric.com, www.westernelectric.com. – Eds]

This project involves an ultra-wide power-bandwidth 300B push-pull amplifier with a Plitron toroidal transformer and Svetlana SV300B matched tubes without NFB. It also includes a driver circuit design by a circuit simulator, in collaboration with Menno van der Veen, a Plitron transformer designer in Holland (via the Internet). Also, using an IAG point-to-point terminal board brought a nice, compact structure of the driver circuit over a small PCB, in order to gain a wider frequency response. The result is a wider power bandwidth of over 150kHz for the first time as a non-NFB 300B push-pull amplifier (*Photo 1*).

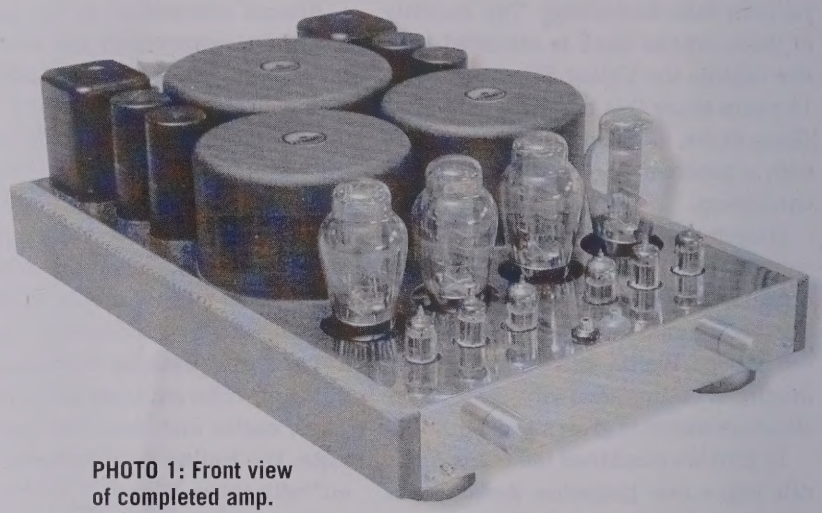


PHOTO 1: Front view of completed amp.

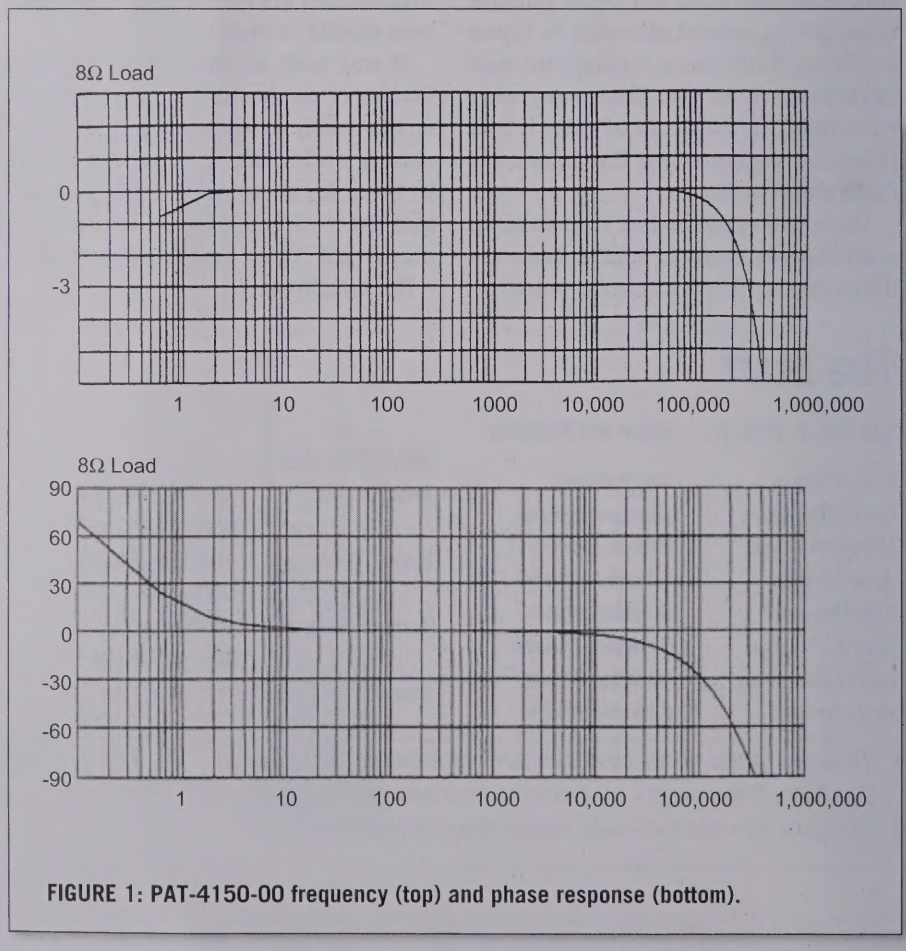


FIGURE 1: PAT-4150-00 frequency (top) and phase response (bottom).

DESIGN GOALS

The following were my design goals for this project:

- Achieve an amplifier with over 150kHz power bandwidth using a toroidal transformer.
- Achieve an over 250kHz and 200V PP phase-splitter driver circuit for 300B pairs.
- Use a final matched pair running at Class-A with a fixed bias circuit.
- Drive a final matched pair directly from the voltage driver using a cathode follower.
- Use non-NFB.

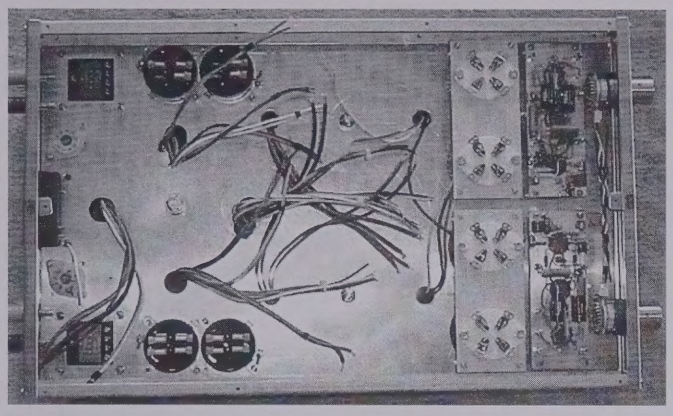


PHOTO 2: Inside view of chassis 300B board; PTP terminal board for voltage driver.

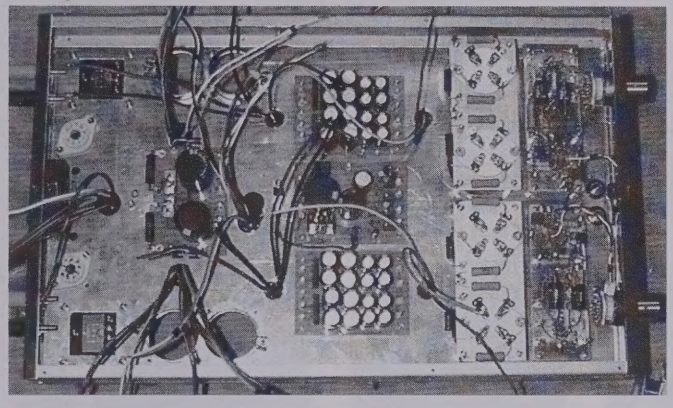


PHOTO 3: Installing 300B hum balancer and power-supply boards.

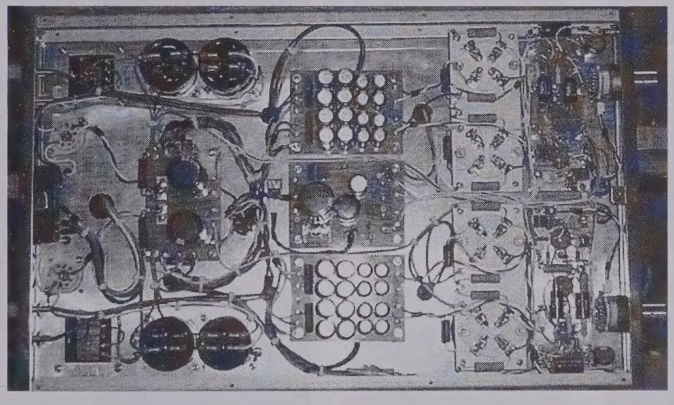


PHOTO 4: Wiring interconnects between boards.

TABLE 1
SV300B OPERATING CONDITION

PARAMETERS	*MJ* 11/99 (*)	SVETLANA SUGGESTED (**)
Power supply	450V	450V
Idle current	60mA	60mA
Average plate current @ maximum signal	109mA	
Maximum plate current @ Vg = 0V	306mA	—
Average plate current	109mA	—
Maximum plate voltage	720V	—
Minimum plate voltage	180V	—
Maximum power output (@ 5% distortion)	41.3W	10W
Plate input power	57W	—
Plate loss (no signal)	27W	27W
Load impedance	3.5kW	5.5kW
Grid bias voltage	–97.5V	–100V
Maximum grid driving signal	200V pp	100V pp

*Push-pull operation
**Single-ended operation

OPERATING CONDITION OF 300B

Up until now, a number of 300B design examples have been published, though most of those are very similar to each other in circuit types and circuit parameters. It will save time to take some examples from the past[1-4]. Coincidentally, references 2 and 3 resemble the design example Svetlana suggested.

As a result, the operating condition of 300B will be –95 to –100V of the negative grid bias, and 60–70mA of idling current at 450V of the plate voltage (*Table 1*).

LOAD IMPEDANCE

This parameter is a headache to define, because there are a lot of choices. A 5kΩ might be a good choice, but I chose Plitron-made toroidal transformer PAT-4135-00 (*Photo 1*), dedicated to 300B push-pull operation, featuring 3.5kΩ load impedance.

VOLTAGE DRIVER

Class-A operation of 300B needs approximately 200V pp ($200 \div 2\sqrt{2} = 70$V) to drive 300B grids. This means that you need a 70–140 gain factor against 0.5V–1V input level, since a negative fixed-bias level of 300B needs approximately –100V DC.

Furthermore, to drive 300B grids directly from the driver stage, a cathode follower (CF) is a good choice for the following reasons.

1. CF offers low-output impedance (a few hundred ohms or less).
2. Direct-coupling eliminates final tubes being cut off due to the excess driving of the AC signal at the final tube grid, when driving final tube grids via a coupling capacitor.

A cathode-follower circuit is driven by a modified differential input stage, because a push-pull needs to provide complementary signals applied to 300B

ABOUT THE AUTHOR

Satoru Kobayashi is from Tokyo, Japan. He has been interested in audio and in ham radio since he was in his teens. After majoring in EE in Tokyo, he joined the semiconductor industry, designing DRAM circuits for a living, although he now works in the technical and marketing area. His debut as a writer came in the early '80s in the form of an article about ham radio for CQ magazine. Now he periodically writes on the subject of audio for a few different magazines. He moved to Austin, Tex. in 2001.

grids. The circuit comes from a book by Menno van der Veen titled *Modern High-End Valve Amplifiers*[5].

The driver circuit consists of a 6N1P and two 5687s lined up in a row. The major reason is that I prefer the good linearity of the 6N1P and low internal plate resistance of 5687, as well as the good sound quality of the 6N1P.

The gain of each stage was verified by a circuit simulator from TUBE CAD by Glassware. The result instantly appeared on my PC screen and was approximately 30×, 7–8×, and 0.94× of gain at each stage, respectively. Overall, you can assume that only 0.35V of input level would achieve the maximum output of 200V PP, which is enough driving level for the 300B with the total gain of 200.

However, the total gain of 200 is too much for the non-NFB amplifier. To adjust this, I installed a 100kΩ volume at the input stage, which uses a DACT-made 24-step volume. For example, the volume compresses the input sensitivity from 0.35V to 1V by five clicks back from the maximum position, which corresponds to 10dB less gain suppression.

I strongly prefer a professional, industrial-made, high-quality attenuator because it offers higher accuracy and frequency response without generating any click noises (compared to resistor film attenuators). Of course, a resistor pair would also offer proper attenuation. It is up to you which approach you prefer to use when you build the amplifier.

The first stage of the 6N1P directly drives the second stage of the 5687. This eliminates an AC coupling capacitor, though the DC plate voltage (approximately 130V DC) must be as high as the sum of grid voltage and the cathode voltage. Thus the plate and cathode voltage of the 5687 must be raised higher than the first stage by 130V.

The cathode follower also directly drives 300B grids, so the node voltage must be identical to the 300B grid voltage. To set this up, a –200V DC power supply is needed and is applied to the 5687 cathode via a 10kΩ resistor. The current flow of 10mA generates a 100V drop over this resistor, applying a –100V DC negative level to the 300B grids.

FIGURE 2: Voltage driver-circuit characteristics and waveforms.

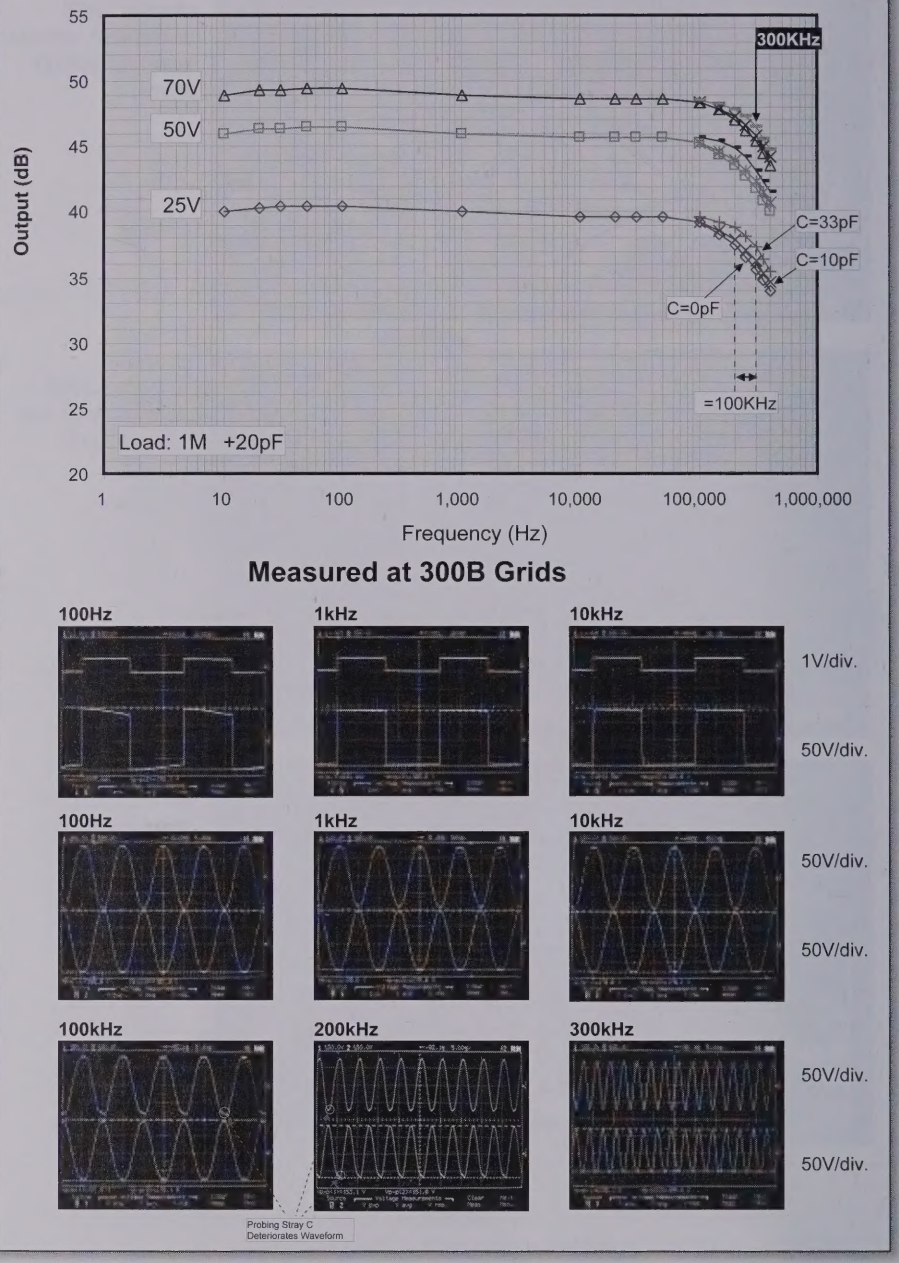
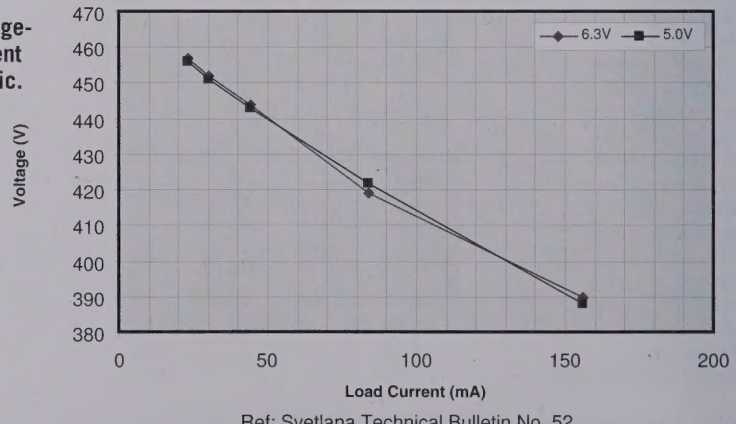


FIGURE 3: 6D22S voltage-versus-current characteristic.



Ref: Svetlana Technical Bulletin No. 52

FIGURE 4a:
Circuit diagram, one channel only.

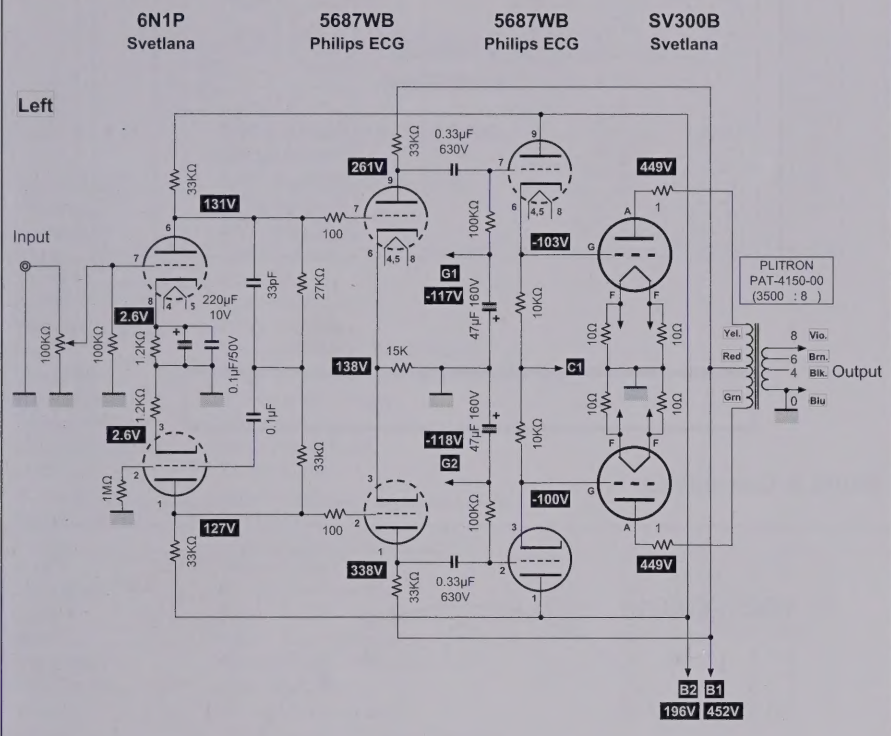
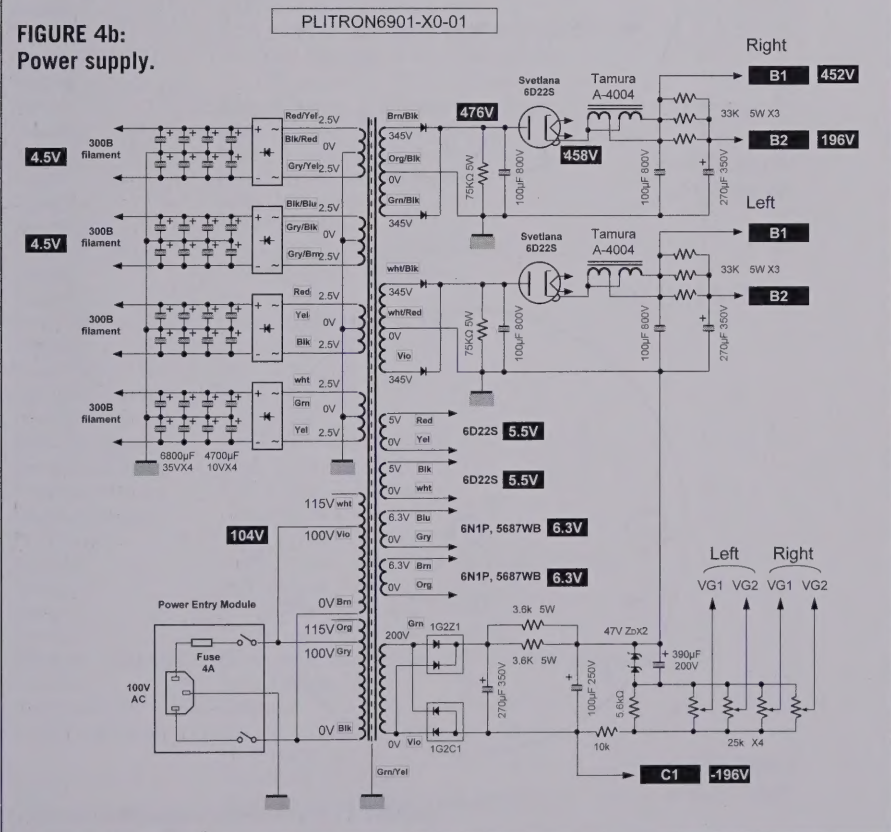


FIGURE 4b:
Power supply.



The 300B grid level is adjusted indirectly by the negative grid level of 5687. The relation between these parameters is Vg level (300B) = Vg level (5687) +10–15V (5687-Vg voltage gap). The 5687 grid level will be approximately –115V. To be cautious, the maximum plate-to-cathode voltage of 5687 is only 300V, so the plate voltage must be no more than 200V for safe use. Overall, the driver circuit needs 200V, 450V, and 200V, respectively, for each stage.

POWER CONSUMPTION

The first and second stages consume approximately 2mA and 5mA per unit of tube, respectively, while the cathode follower consumes 10mA by simulation. The total consumption per channel is $(2 + 5 + 10) \times 2 = 34$mA.

PHASE SPLITTER

The phase inversion (phase splitting) to make complementary signals to drive the 300Bs was accomplished by returning the summing node out of both plates of the 6N1P via the resistor pairs (33kΩ, 27kΩ) to a grid of the other 6N1P unit through a 0.1μF capacitor. You can adjust the AC balance by tuning this feedback resistor pair, although the measured complementary output signals were well-balanced with a difference of less than 3 percent even at the maximum output. Thus, I omitted an AC balancing volume from this design.

FREQUENCY COMPENSATION

This design was able to maximize the frequency response of the toroidal transformer over 150kHz. Reference 6 contains a frequency-compensation capacitor connected in parallel to a feedback resistor of 33kΩ; this enhances the gain in the frequency range between 150kHz and 200kHz. Reference 5 shows that the capacitor for this purpose might be only several pF, though. I tried to see the change by applying both 10pF and 33pF dipped mica capacitors–saved in my parts box–to 33kΩ in parallel. *Figure 2* shows the result of this experiment.

The 33pF feedback capacitor produced the widest frequency response, which is 100kHz wider than the other

one. The high-end cutoff frequency reached 300kHz at the driver stage. The output maximum voltage reached approximately 200V PP. These results can verify that all design parameters are good enough to drive 300B matched pairs.

POWER SUPPLY

Plitron in Canada has recently developed a toroidal power transformer for 300B push-pull amplifiers. The 6901-X0-01 is a newcomer to their product line. This unit measures 18cm in diameter, weighs 8Kg, and provides a couple of separate plate-supply windings, making independent B+ power supplies for both channels of 300Bs.

After rectification by a couple of Schottky diode pairs, a Tamura-made choke coil of A-4004 mates with this toroidal transformer by height. Its case color is gray, but I painted it black with acrylic spray paint.

The total power consumption would be 252mA (109 × 2 + 34), so the other A-4003 model (5H250mA) by Tamura could replace the A-4004 choke coil.

I used a Svetlana 6D22S in series with this rectifier circuit, mainly because the 6D22S features a 30-second heat-up time; this feature is a timer that secures the safe operation of 300B power tubes. A B+ power supply at the 300B plate node turns on after 30 seconds with a 6D22S-timer switch.

The 6901-X0-01 does not provide any other 6.3V tap for 6D22S, which must be heated up by a 5V tap. It scares me that the 6D22S could work securely under 5V operation. However, Svetlana s technical bulletin No. 52 has eased my mind. *Figure 3* certifies that the 6D22S works securely even at 5V, because the performance difference between the 5V and 6.3V supply is negligibly small.

The negative power supply for the cathode follower comes from the full-wave rectification of a 200V AC tap using a conventional resistor and capacitor filter circuit to generate 200V DC. The positive node of the 200V DC power-supply board is grounded; consequently, a –200V DC negative node over a PCB becomes active to drive a cathode-follower circuit. The parallel-connected couple of 3.6kΩ resistors

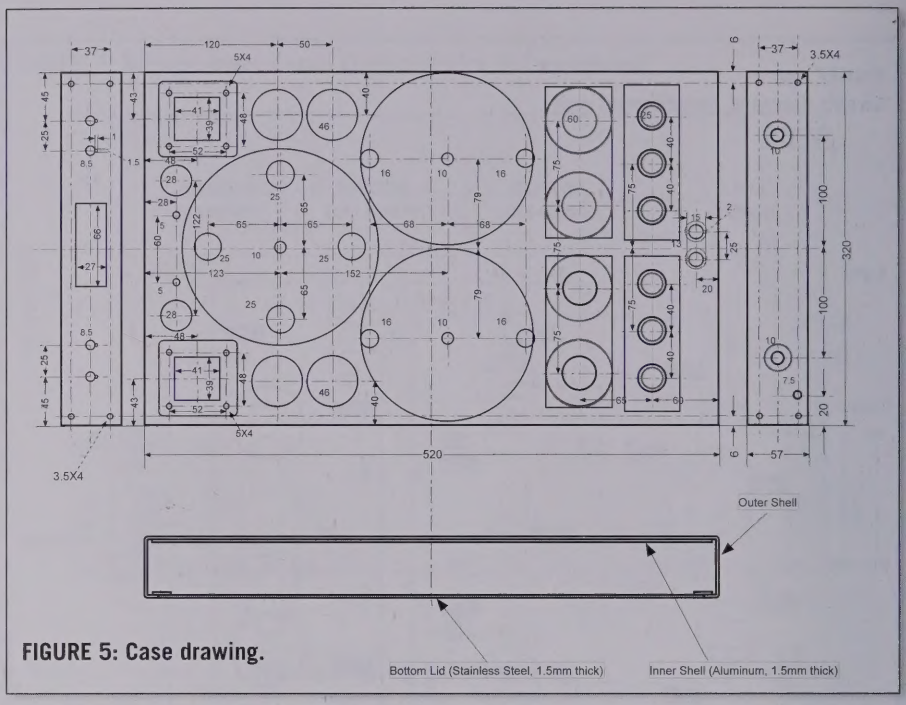


FIGURE 5: Case drawing.

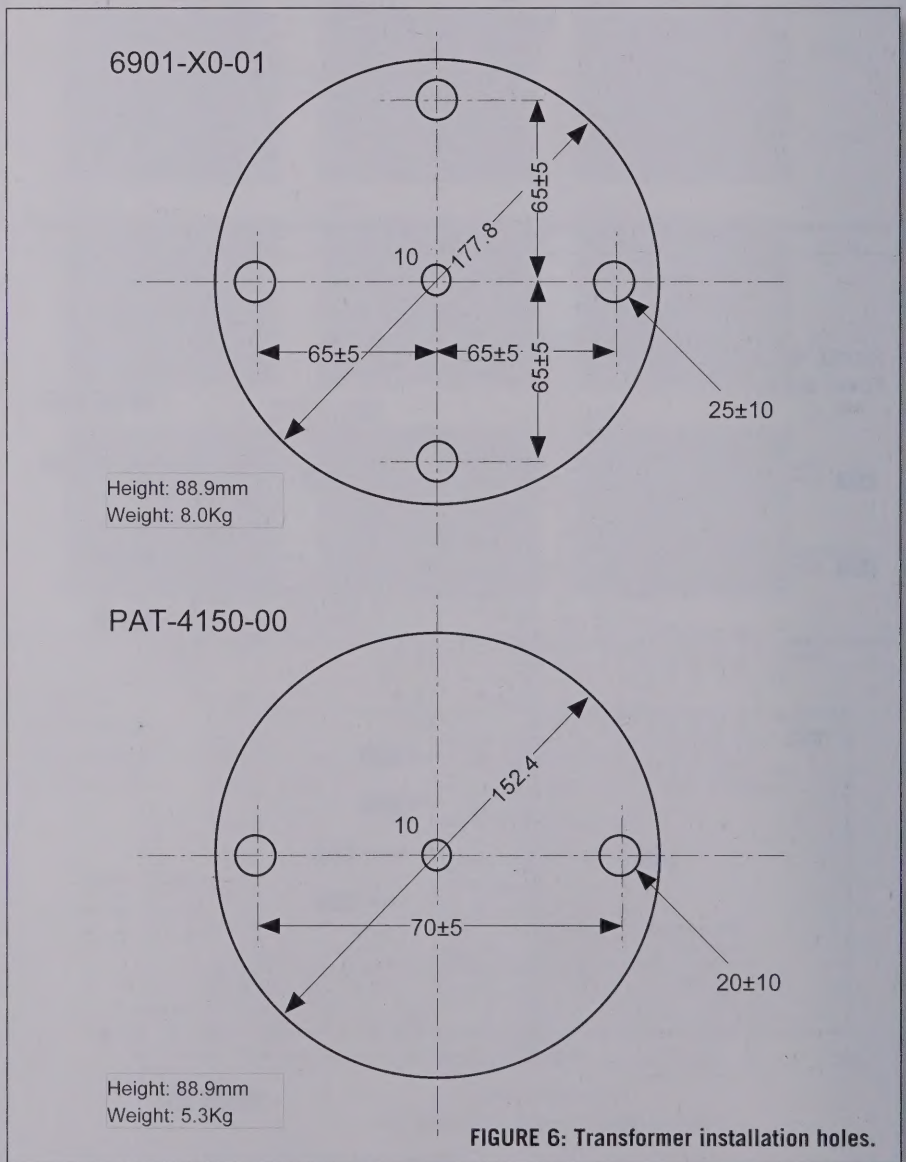


FIGURE 6: Transformer installation holes.

can adjust this negative power-supply voltage.

Each grid node of the 5687 cathode followers is independently adjusted with four independent pots installed over a PCB, which enables the control range between –95V and –125V with a cascaded 47V zener diode.

TABLE 2
PARTS LIST

ITEM	SPECIFICATION, MANUFACTURER, MODEL NUMBER	QUANTITY
Vacuum tube	SV300B matched pair (Svetlana)	2
Vacuum tube	6N1P (Svetlana)	2
Vacuum tube	5687 (Philips ECG)	4
Socket	4 pin UX socket	4
Socket	9 pin USA	6
Socket	9 pin SK509 (Svetlana)	2
Plate cap	PC509 (Svetlana)	2
Case	520 × 320 × 57mm, San Ei Musen	1
Fuse/switch	Power entry module, IEC standard, Delta made	1
Power cable	Hospital grade 3m long	1
Power transformer	Plitron 6901-X0-01	1
Output transformer	Plitron PAT-4150-00	1
Choke coil	Tamura A-4004	2
RCA jack	San-Ei Musen	2
Speaker terminal	San-Ei Musen	2
Volume	100kΩ (A) DACT made CT-1-100K	2
Knob	Stainless milled, DACT	2
Zener diode	47V 3W 3Z47 Toshiba	2
Diode	1200V 1A, 2NU1 Toshiba	2
Diode	1G2C1, 1G2Z1 Toshiba	1
Bridge diode	D10XB60H 60V10A Sanken	4
Potentiometer	25kΩ (B) Bourns	4
Resistor	1Ω 1W 1% wire-wound	4
Resistor	10Ω 3W metal film oxidized, Matsushita	4
Resistor	100Ω ½W carbon	4
Resistor	1.2kΩ 1W carbon, A&B	4
Resistor	3.6kΩ 5W metal film oxidized, KOA	2
Resistor	5.6kΩ 1W carbon	1
Resistor	10kΩ 1W carbon	1
Resistor	10kΩ 3W metal film oxidized, KOA	4
Resistor	15kΩ 3W metal film oxidized, Matsushita	2
Resistor	27kΩ ½W carbon, or 1W metal film oxidized	2
Resistor	33kΩ ½W carbon, or 1W metal film oxidized	2
Resistor	33kΩ 1W carbon, or 1W metal film oxidized	4
Resistor	33kΩ 3W metal film oxidized, Matsushita	8
Resistor	33kΩ 5W metal film oxidized, Matsushita	6
Resistor	75kΩ 5W metal film oxidized, Dale	2
Resistor	100kΩ ½W carbon	6
Resistor	1MΩ ¼W carbon	2
Electrolytic capacitor	100µF 800V, RU-Z, Mylar film, Shizuki made	4
Capacitor	33pF dipped mica, 500V Nittsuko	2
Capacitor	0.1µF 50V film	2
Capacitor	0.33µF 630WV Angela or Solen	4
Capacitor	0.1µF 250WV Mylar film	4
Electrolytic capacitor	47µF 160V	4
Electrolytic capacitor	390µF 200V	1
Electrolytic capacitor	100µF 250V	1
Electrolytic capacitor	220µF 10WV Sanyo capacitor	2
Electrolytic capacitor	270µF 350WV Nichicon	3
Electrolytic capacitor	4700µF 10WV Matsushita	16
Electrolytic capacitor	6800µF 35WV Marcon	16
Pin terminal	Teflon insulated	
Metal feet	Aluminum milled, 65mm dia, 20mm height, IAG made	4
Spacer	3mm diameter, 10mm long	16
Spacer	3mm diameter, 30mm long	8
5⁄16″ bolt	2″ long, comes with Plitron transformer	3
Pilot lamp	5V ultra bright blue LED, DUL-7HJT Sakazume Seisakusyo	1
Hook wire	Teflon insulated	
Heat shrunk tube	Sumitomo	
Wooden side panel	200 × 57 × 12mm, oak wood, Tokyu-Hands	2
PTP terminal board	140 × 50mm IAG made	2
PCB	100 × 75mm, 100 × 65mm 1.6mm thick	4

All driver-tube filaments are tied together per channel using an independent tap of 6.3V. Since the driver circuit uses a direct connection between the first and second stage, and the final stage uses a cathode follower, the cathode node level of each stage reaches either 150V or –100V, which exceeds the maximum voltage limit of cathode-to-filament voltage of ±100V. To get rid of this excess condition, an adequate DC bias to the filament could minimize the gap of cathode-to-filament voltage. But the lack of additional 6.3V wiring could not solve this issue, so you might leave this alone.

Four center-tapped 2.5V AC windings generate four independent ±2.5V DC nodes with a 44,000µF electrolytic capacitor to drive 300B filaments after a full-wave bridge rectifier. The filament voltage becomes approximately 4.5V DC due to the forward voltage drop of the silicon diode. At last, the circuit has reacted to the goal shown in *Figs. 4a* and *4b*.

PARTS LIST

The major parts such as Svetlana valves and Plitron transformers, as well as a "Shizuki"-made electrolytic Mylar film capacitor, came from Tec-sol Inc. in Hamamatsu, Japan. This capacitor features 1) non-polarity, since a Mylar film is used, 2) greater durability against a larger ripple-surge current than a regular capacitor, and 3) less leakage current. Some hold that these features will enhance the sound quality when implemented in the high-end tube amplifier. Furthermore, the maximum working voltage of 800V is rather high compared to the 500V of a regular product, so it would be adequate even for a transmitting-tube amplifier such as the UV211, 845, and SV572.

The drawback is its larger size—46mm diameter and 120mm height—though it fits nicely with the Plitron toroidal transformer in this floor plan.

I custom-designed the case, which was built by San-Ei Musen in Tokyo (unfortunately, since publication of this article, they have closed their business). The case design offers several features: 1) the shell structure with its outer and inner case mates snugly with several screws over the front, rear, and

side-wall panels; 2) the structure of the top two-layer plates hides a number of screws securing sockets, PCBs, and others out of the top plate; 3) the bottom plate also sits snugly into the case, producing the perfect shell structure so that the heavy transformers sit securely on the top plate.

IAG in Texas made polished aluminum feet for the bottom plate mate neatly with this case. DACT-made stainless-steel knobs fit perfectly into the panel. Also, a stainless-steel top plate eliminates the need of painting and saves manufacturing cost and time.

The Svetlana 6N1P has become popular in the tube audio area. It improves the sound quality as a replacement for the 6RHH2 in a preamplifier, and has produced greater clarity and strength of sound.

The second and the final stages use the NOS 5687WB tube by Philips ECG, which came from my parts box. The other components are from parts shops in Akihabara. *Table 2* shows the parts list of this amplifier.

ASSEMBLY

I used Power Macintosh G3/300MHz and Claris Draw software to design the case, which measured 520 × 320 × 57mm, placing major components symmetrically over the case against the centerline. I placed the power transformer at the center, with a couple of choke coils, 6D22S tubes, four filter capacitors, and a couple of output transformers peripherally around it.

The case thickness of 57mm is about the same as the line amplifier I introduced before, so that this amplifier and the line amplifier could line up in a row, when placed side by side. *Figure 5* shows the drawing schematic for reference.

I placed the final 300B tubes over the steel-plate sub-chassis, about 3cm beneath the stainless-steel top plate, inserted in four-pin UX sockets. Since the 300B tube is higher than the transformers and chokes, this arrangement levels the height of the major components with each other. The top plate provides 6cm-diameter holes for cooling the 300Bs.

The oak panels attached to the side-

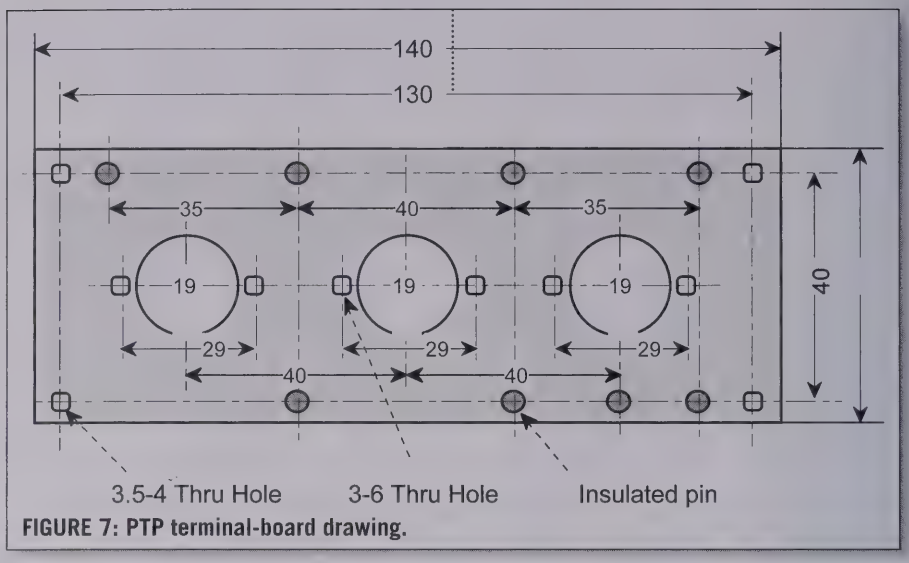
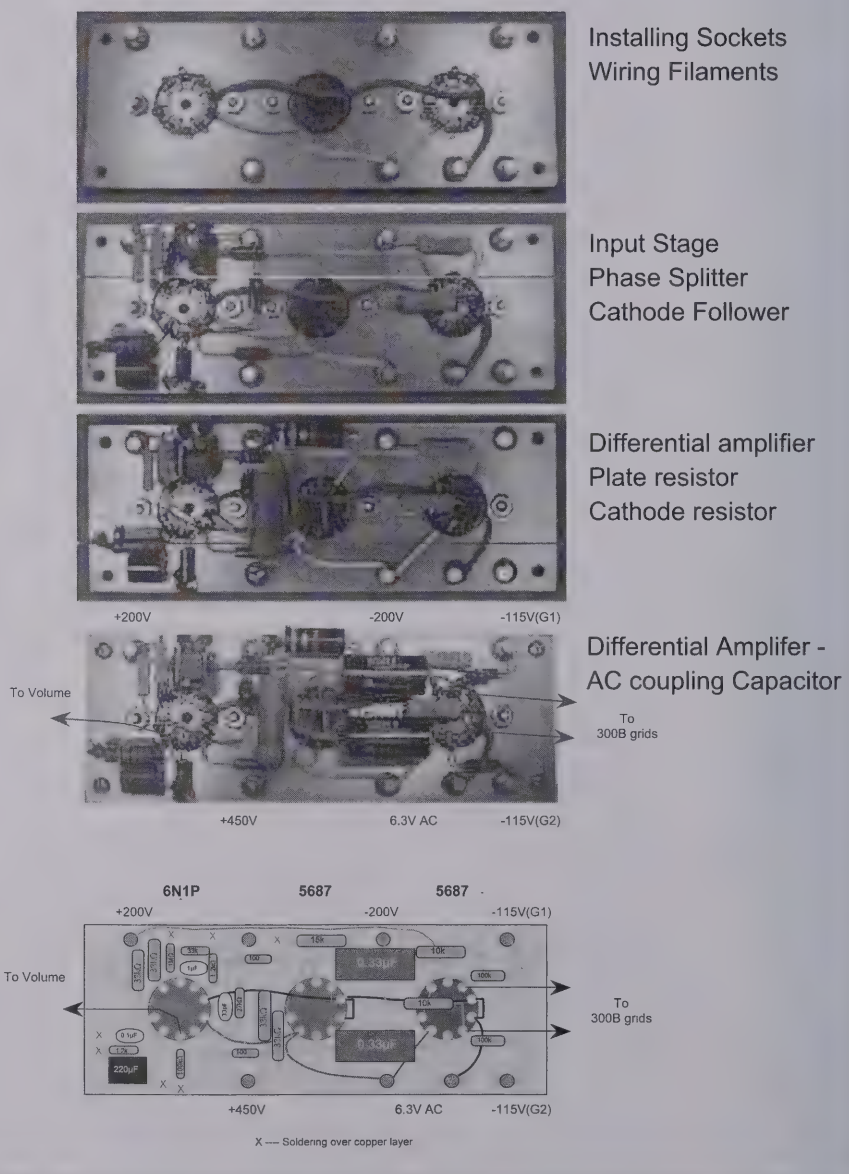


FIGURE 7: PTP terminal-board drawing.

FIGURE 8: PTP terminal-board assembly process.



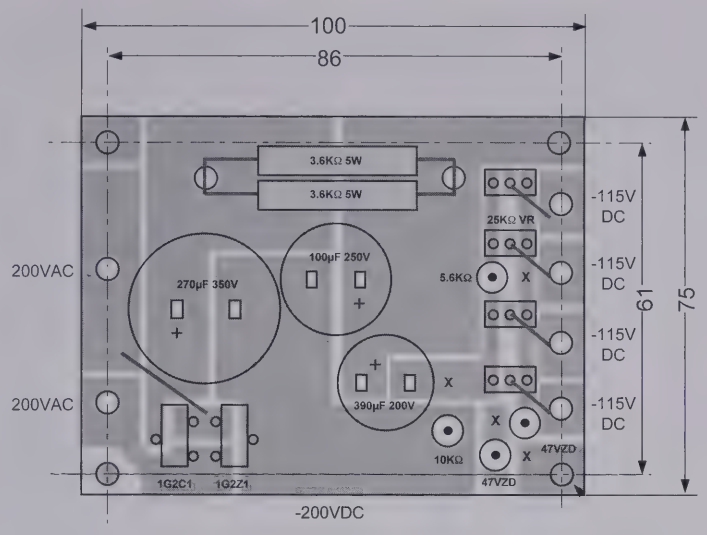
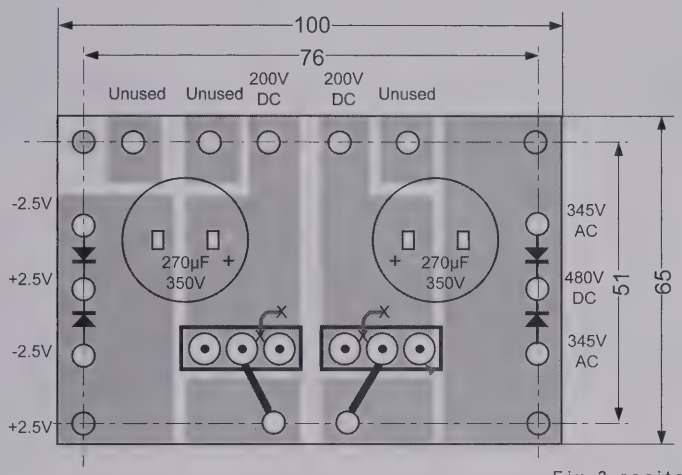


Fig-9a -200V, -115V Power supply

4mm Thru Hole



Fix 3 resitsors perpendicularly on PCB with a small chunk of PCB on the top of those by soldering.

Fig-9b +200V Power Supply

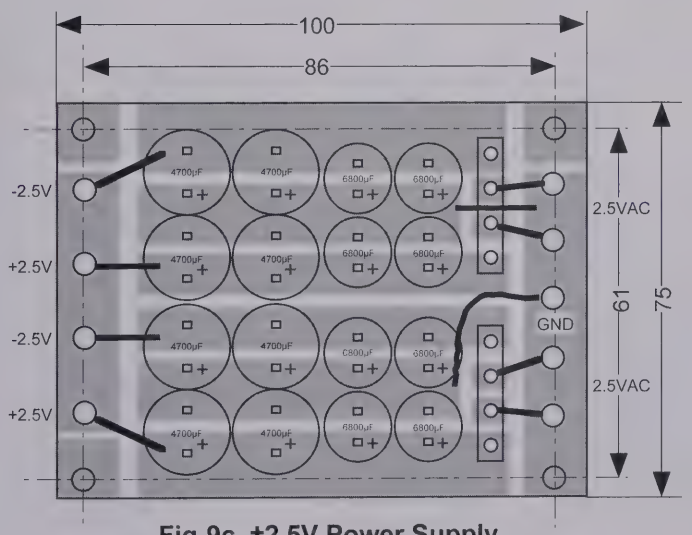


Fig-9c ±2.5V Power Supply

FIGURE 9a, b, c: Power-supply boards.

wall lends warmth to the amplifier in a listening room. The side oak panel sized 520 × 57mm with a 12mm-thickness was cut by the DIY shop of Tokyu-Hands in Shinjuku, and polished with #240 and #600 sandpaper, oil-stained, and finished with non-glossy clear paint after drying.

INSTALLATION

First of all, affix the wood panels using wood screws over the side panel. Then attach the major components over the top plate, from lightweight components to the heavier ones such as transformers (*Fig. 6*). Finally, attach power-supply boards, the sub-chassis for the 300B tubes, and the PTP boards to spacers over the top plate (*Photos 2–4*).

VOLTAGE DRIVER

Due to the smart PTP board, the entire driver circuit turned into a module, measuring 140 × 50mm × 3.2mm-thick copper-clad board. I custom-designed this myself. Thanks to Mr. Atkinson at IAG Group in Texas for his good service and for sending me my custom-designed board in a couple of weeks after placing my order via the Internet. All of the parts for the driver circuit were mounted and wired on a PCB prior to its assembly into the case without any extra hookup wire (*Fig. 7*). This enhanced the frequency response and provided a compactness of the circuit, offering three-dimensional wiring (*Photo 5*). *Figure 8* shows the assembly sequence of the PTP board and an actual wiring schematic. Upon assembly completion, double-check the wiring to see whether or not it is correct and shorted carefully.

POWER SUPPLY

I mounted the B+ 200V, C-200V, and ±2.5V DC filament supplies on PCBs, measuring 10 × 7.5 and 10 × 6.5cm. To simplify wiring on the PCBs, I also mounted extra Teflon-insulated pins. Use a utility knife to cut a straight line of the circuit pattern (*Figs. 9a, b, c*). These boards are attached beneath the toroidal transformers with 10mm spacers.

INPUT STAGE

The input signal comes in through an RCA jack over the top plate, and goes to

the grid pin of 6N1Ps via the DACT-made volume control with a three-pin PCB connector. The physical alignment of this component made the hookup wires short, so no shielded wires were necessary.

FINAL ASSEMBLY

Final assembly was easy because the major electronic components were mounted over the PCB and PTP boards. Once these are installed beneath the top plate with insulated terminal pins, the final assembly requires only tying these terminal pins with hookup wires. After the assembly, internal hookup wires between modules are bound with a color binder strap.

ADJUSTMENT

First, double-check for correct wiring inside the chassis. Without inserting any tubes, turn the power switch on. Check the C-grid bias voltage at each of the 300B grid pins to see the node voltage below –120V DC, by turning the pot to the minimum on the PCB. After this, turn the power switch off, insert driver tubes other than the 300Bs into the sockets, and then turn the power switch on again.

Measure filament voltage of the driver tubes and the 6D22S, respectively, which would be 6.3V and 5V within 10% tolerance. The B+ power-supply voltage should be over 450V DC. Turn the power switch off and plug the 300B tubes into the sockets.

Once again turn the power on, and, after a few minutes, measure the voltage drop over the 1Ω resistor located at the plate electrode of the final tube, using a digital multimeter, and tune the grid-bias pots so that the voltage drop is 60–70mV. After about half an hour, measure the voltage drop again to verify the stability. Finally, the negative grid-bias voltage should be –100V.

MEASUREMENT

During assembly, I measured the voltage-driver characteristics, paying particular attention to the stray capacitance and the input impedance of the measuring probe. Even in a cathode-follower circuit, the input capacitance of 70pF using a conventional AC voltage meter would influence the frequency-response measurement beyond 100kHz. To minimize this input stray capacitance measuring error, I used an HP54600B digital-readout oscilloscope with a 1:10 voltage probe (1MΩ + 20pF). Thus, the amplifier s V PP and V RMS of the output signal were measured in more detail than ever before.

The total gain was approximately 200 (*Fig. 10*). The linearity attained was up

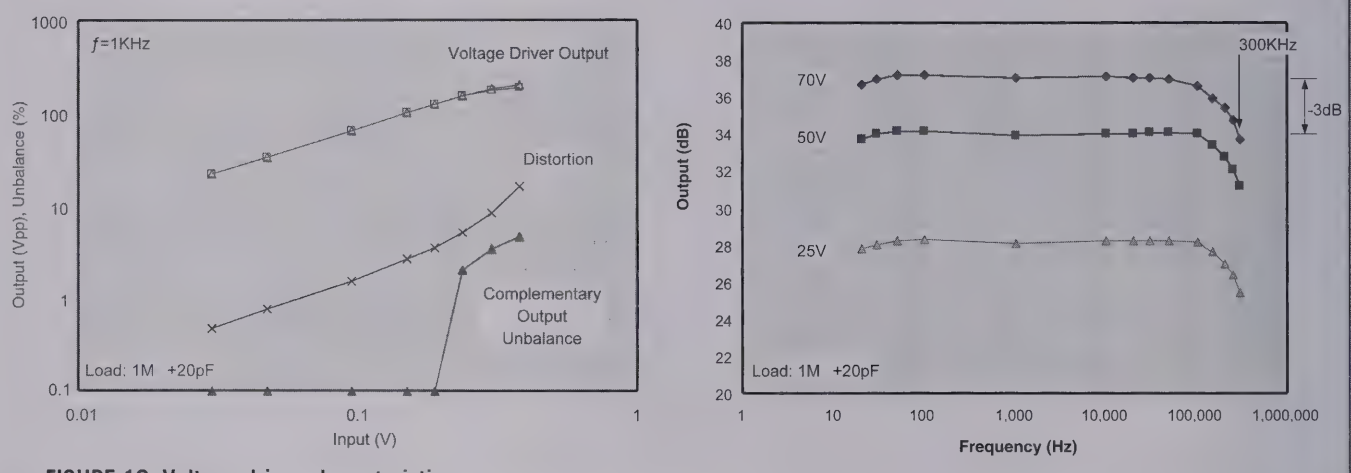


FIGURE 10: Voltage-driver characteristics.

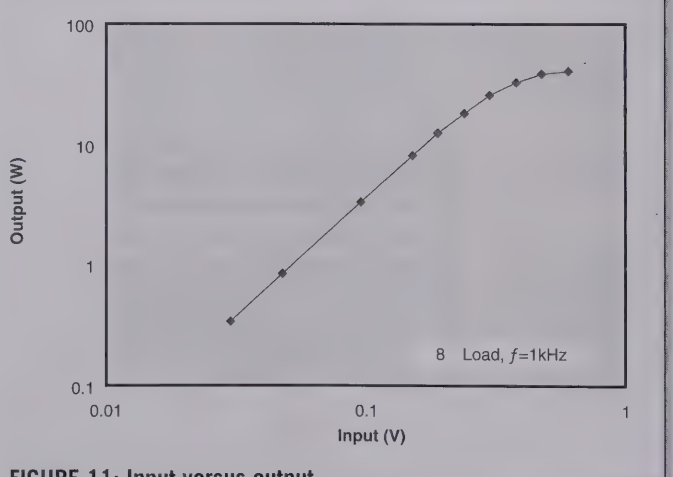


FIGURE 11: Input versus output.

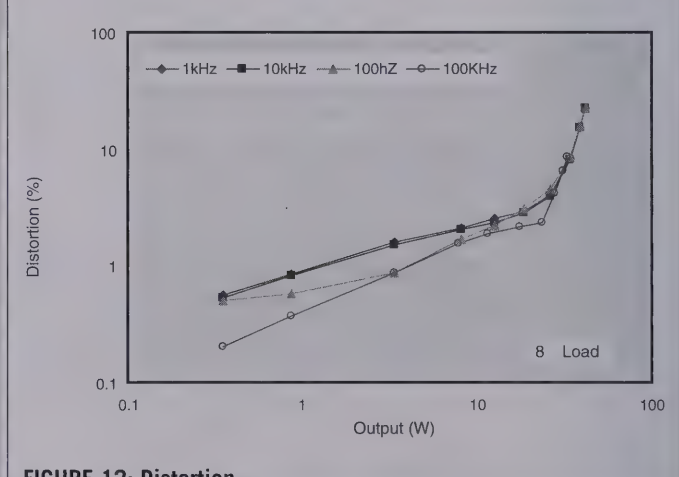


FIGURE 12: Distortion.

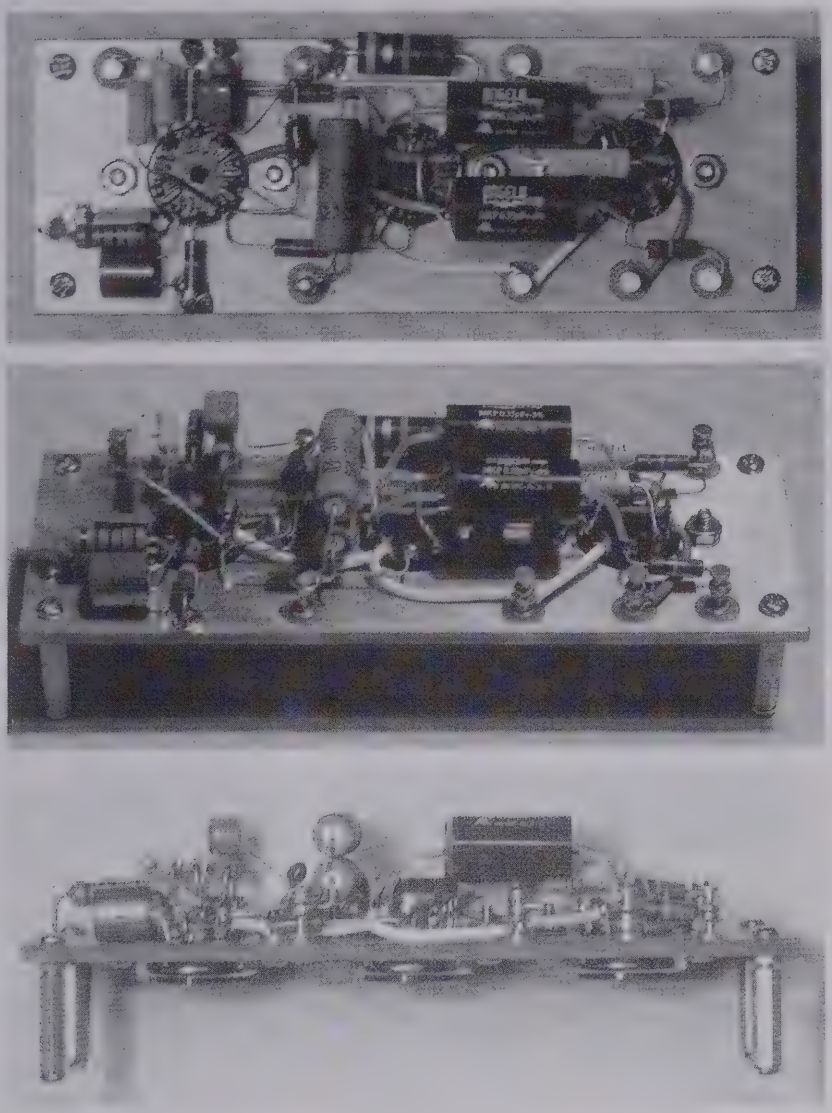


PHOTO 5: Voltage driver module, using PTP terminal board.

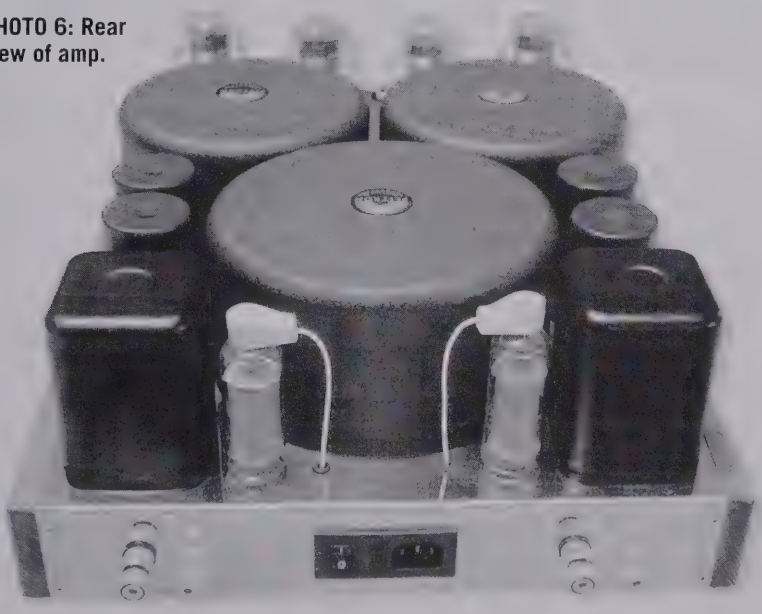


PHOTO 6: Rear view of amp.

to 150V PP or more. The frequency-response curve shows up to 300kHz at the –3dB level. The maximum output level was approximately 200V PP at the input of about 0.3V, guaranteeing enough driving capability.

INPUT VERSUS OUTPUT

The input sensitivity was approximately 0.3V, producing a maximum output of 24W. The linearity showed up to 15W, though the overall linearity looks very good (*Fig. 11*).

DISTORTION

Since the driver circuit showed an over 100kHz frequency-response curve, I measured the distortion curve at 100kHz, showing lower than that of 1kHz. *Figure 12* also shows the typical tendency of a triode tube amplifier: the distortion increasing linearly. The estimated maximum output power would be more than 25W, defining the output power at a distortion of 5%, which meets the results of the design example shown in Reference 2.

The overall distortion showed a rather larger value than that of amplifiers I ve seen in the past because of non-NFB. However, the distortion measures below 2% or so in the range of regular use: below a few watts.

FREQUENCY RESPONSE

The high-end cut-off frequency was in the range of 170–200kHz at 1W, 10W, and even 25W under non-resistive 8Ω loading (*Fig. 13*). This is an extremely wide frequency response for a non-NFB 300B push-pull amplifier.

DAMPING FACTOR

The damping factor was 1.7 by the on-off method with 8Ω loading at 1W (2.83V RMS). *Figure 14* shows the peak response curve at 150kHz, which is uniquely characteristic of the Plitron toroidal transformer.

OUTPUT WAVEFORM

I took the oscilloscope images in *Fig. 15* at the output power of 25W, showing a clean shape of square wave without any ringing. Even at a heavier capacitor loading of 1μF, I observed no waveform deterioration, implying a stable driving capability for the speaker

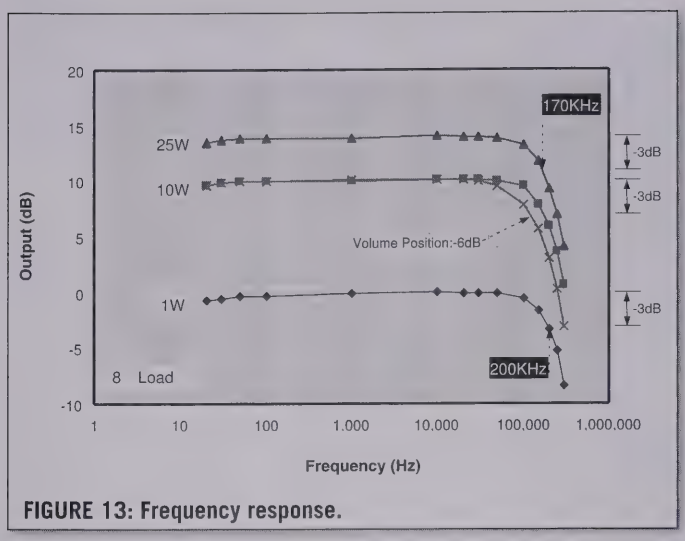


FIGURE 13: Frequency response.

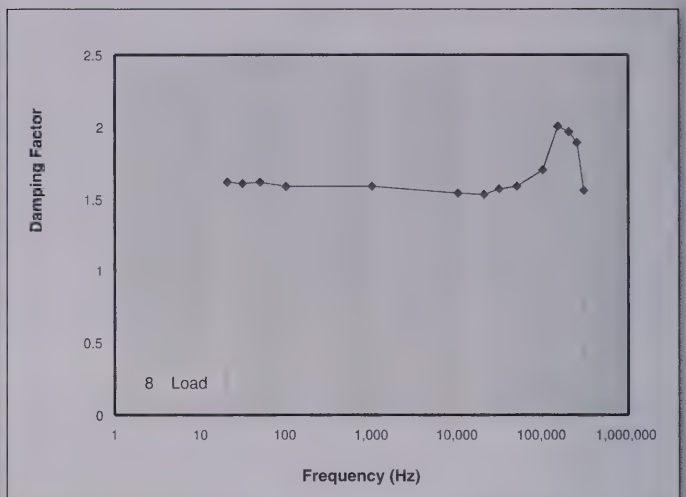


FIGURE 14: Damping factor.

systems. This tendency of the toroidal transformer is unique and completely different from the conventional E-I cored transformers.

Even the 100kHz square waveform clearly shows a good shape, as if it were measured in a digital circuit. Also, the 200kHz sine wave was neatly shaped without any visible decay in a waveform, though the delay (i.e., a phase shift from the original input signal) shows approximately 2µs, as though it were the phase inversion.

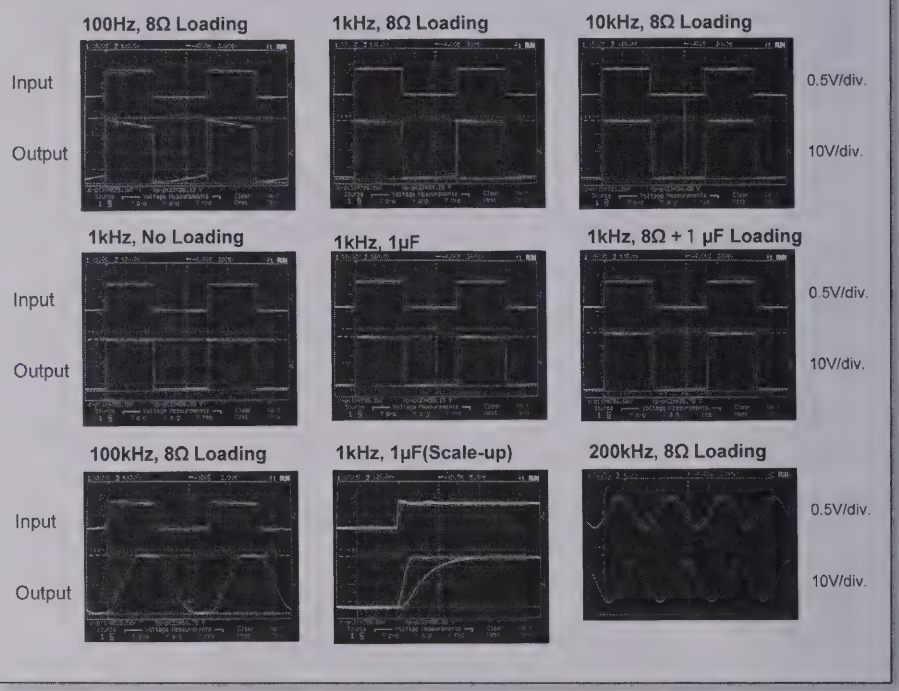
RESIDUAL NOISE VOLTAGE

The residual noise voltage at the output terminal was 1.5mV, which generated a very low level of hum at a distance of 1m away from the JBL S3100 speaker system. I guess this is a good enough value for a non-NFB amplifier, but there is still room to reduce this value. You might check the grounding point of a center tap of the filaments over the internal case. Careful tuning, such as below 1mV, might improve this noise voltage.

LISTENING IMPRESSION

As a reference, I used my own system: TEAC VRDS-50 CD player, homebrew 6N1P line amplifier, and B&W 802 speaker system, with my homebrew 300B single-ended amplifier. My first impression right after turning on the CD player was "dynamic and powerful," because the amplifier produced an extremely big sound from the speaker at the same volume position of my line amplifier.

FIGURE 15: Waveform.



In comparison with my 300B single-ended amplifier, the vocal sound comes out more upfront than the reference amplifier. In particular, female vocal singers emerge apparently and distinctively more toward me than ever before. The orchestral music had more presence than that of the single-ended amplifier, as though I could picture where each musical instrument could be individually placed on the invisible stage of the concert hall in my brain. The low tones are much stronger than that of the single-ended amplifier.

It seems clearer than even in the high tones, though the difference between the single-ended amplifier is negligibly small. The strings of an acoustic guitar (played by Eric Clapton, for example) sound more realistic and stronger than that of the reference amplifier, enhancing the low tones.

I believe that the toroidal transformer brings more clarity, strength of low-tones, and so on, compared to the conventional E-I cored transformer. I suggest that whoever wishes to taste this new sound should try this one on (*Photo 6*). I guarantee the sound quality. ❖

The 33 Power Amp

Flexibility is the keyword for this modest tube-based power amp. A project well worth tackling. **By John Stewart**

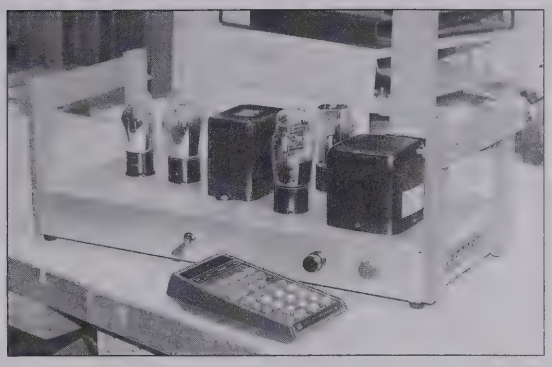


PHOTO 1: The 33 Power Amp.

Finally, a vacuum tube amplifier that those living far from a power line can enjoy (*Photo 1*). Requirements are so modest that you can use it in the backwoods or on an island where the power system may be solar or wind-operated. When operated from a domestic power source, it needs only 20W. If you were to operate from a DC source, then 15W does it. It will not help to heat your house, as do so many of the tube amps now in use.

BACKGROUND

Many years ago as a child, like so many others I became interested in electronics. After a time, I moved from crystal radios to vacuum tubes. These included the 201A, 264, and some WE globular triodes, the kind we would sell our soul for today. They managed to eat batteries rather quickly. I wasn't very kind to them, either.

Later I became acquainted with such tubes as the 1H5GT and 1N5GT, which helped solve the battery problem. They needed only 70mW at the heater. I even managed to drive a loudspeaker by using a beam tetrode, the 1T5GT.

Soon after, my mother allowed me to connect to the power line, and I never again had reason to use or experiment with tubes intended for battery operation. However, during all of the succeeding years, I remained curious as to what could be done with battery-operated tubes.

A sale flyer from Antique Electronics offering a Hammond 269EX power transformer at a good price pushed me over the edge. I just had to see what could be done. This is it.

ABOUT THE AUTHOR

John Stewart, a professional Engineer (Electrical) has finally retired after 35 years in the sales arena, primarily with Rohde & Schwartz and Hewlett-Packard. He gained design experience with vacuum tubes while working for the University of Toronto, Physics in the '50s and '60s.

CIRCUIT FEATURES

1) Operation in triode or ultralinear mode
2) No external feedback
3) Soft start/standby and run modes
4) Excellent performance
5) Low cost

TRIODE OR ULTRALINEAR?

You can make this decision for yourself. You can easily change wiring of the output transformer to suit your personal preferences. In triode mode you can expect about 2.5W of power. Damping factor measured two. In the ultralinear connection 4.5W output is possible. Damping factor drops to one. This used to be called "unity damping."

Many articles were written and published covering the pros and cons of unity damping in the '50s and '60s. Some of the better amplifiers actually came with a control that allowed adjustment of the damping factor. This was achieved by varying both the normal negative voltage and separate positive current feedback networks. Not recommended for amateurs.

Don't use a switch to compare triode to UL operation. When the output tube screen grids are unhooked from the power supply, a large voltage transient occurs which can easily destroy an expensive output transformer, as well as the switch. All power sources should be unhooked and the wiring physically changed.

The amplifier and power supply are shown separately for clarity. A performance summary is given in *Table 1*. You should note in particular the very low levels of distortion higher than the third harmonic. That is because the driver stage is not coupled by capacitors to the output stage. Clipping is avoided along with the higher-order harmonics and blocking.

TUBE SELECTION

I did a survey of tubes which would be suitable for this project. I rejected those that run in Class B, since that type of circuit is notorious for generating distortion at low levels. The 33 was most promising for the output and driver stages because of its rather large filament. Gain from the grid of the driver stage to its plate is about 4.5.

Other tubes that might be suitable for the driver stage are the 31 and 1H4G. However, they may not be able to fully drive the output stage into Class AB2 without generating distortion in the output grid circuits.

As far as I was able to tell, there were no high-mu triodes in the 2V series. As a result, I selected the medium-mu triode 1B5/25S as the input voltage amplifier for this project. The input stage has a gain of about 15.

I did not include a gain control on this amp, since I would normally include that in a preamp. If you like, you could replace R1 with a gain control. You will need 0.75V RMS at the input to get full output. *Table 2* gives a summary of the characteristics of the tubes I used in this project.

AMPLIFIER CIRCUIT DESCRIPTION

At first look, the circuit appears to be fairly ordinary (*Fig. 1*). The output stage is completely transformer-coupled so that it can be driven into Class-AB2. The output transformer I used is something I bought many years ago and did not use at the time. A Hammond 1609 will work OK in this position.

If you have ever wondered about instability attributable to ultralinear coupling, you can find a worthwhile read in Norman Crowhurst's book *Audio Measurements*[1]. It is well worth the price of admission.

The interstage transformer shown in *Photo 2* is a Hammond 447 that is no longer available. Again, you can assume I've had it for a long time. The 447 has a small stepdown ratio of 1.5:1 from the plate winding to each of the grid connections. It is meant to drive a Class-B stage.

It worked OK, but I soon realized it was not optimum to drive the output 33 grids. Available plate swing from the triode-connected 33 driver was insufficient to get full output when using the 447.

A Hammond 448 originally designed to drive a Class AB stage with its small stepup ratio of 1:1.25 would be better. It, too, is no longer available.

After several e-mails and telecons, Hammond provided the answer. It is similar to their original 448 but with improved frequency response. Their part number is H300759. The plate impedance needs to be about 6k.

It doesn't need to have response from DC to green light like you see in some of the stuff on the market today. That's because it is not inside a feedback loop. Again, you could refer to Norman Crowhurst's[2] articles covering his twin-coupled amplifier design. See the parts list (*Table 3*) for recommendations.

If you want to avoid a rather complicated power supply, then the biasing network needs careful attention. Since these tubes do not have separate cathodes, the use of cathode biasing resistors is inconvenient. If you did, you would need a separate DC supply for each of the 2V filaments.

The biasing network consists of the resistors R10, R11, and R12, along with the capacitor C3. Current from all of the tubes passes through

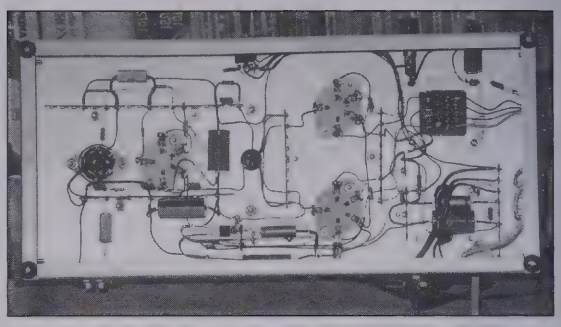


PHOTO 2: Bottom of unit.

FIGURE 1: 33 Power Amp.

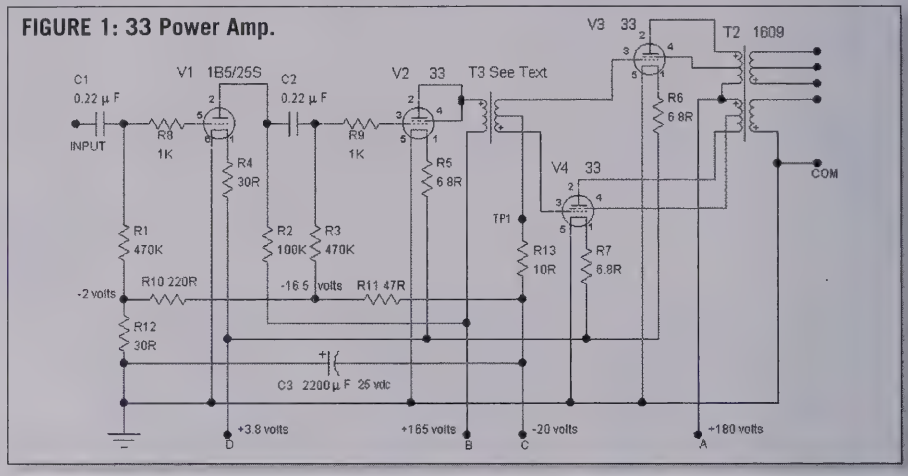


TABLE 1
33 POWER AMP PERFORMANCE SUMMARY

PERCENT DISTORTION AT WATTS OUTPUT

CONDITION						
A) ULTRALINEAR CONNECTION		1	2	3	4	4.85 MAX
HARMONIC	2nd	~	0.05	0.20	0.45	0.53
	3rd	0.47	0.91	2.70	5.07	6.90
	4th	~	~	0.13	0.11	0.09
	5th	~	~	0.32	0.40	0.10
Moves to Class-AB2 at 2.35W output						
DAMPING FACTOR	@ 1kHz	1.57				
	@ 60Hz	1.68				
B) TRIODE CONNECTION		1	2	2.5 MAX		
HARMONIC	2nd	~	0.29	0.63		
	3rd	0.06	1.64	2.56		
	4th	~	0.12	0.18		
	5th	~	0.38	0.09		
Moves to Class-AB2 at 1.06W output						
DAMPING FACTOR	@ 1kHz	2.69				
	@ 60Hz	2.61				

C) Distortion comparison before and after output tubes were switched. Comparison taken at 1W output, ultralinear connection.

		BEFORE	AFTER
HARMONIC	2nd	0.30	~
	3rd	0.48	0.47

D) Frequency response is 3dB down from the 1W level at 30Hz and 30kHz. It is most dependent on the interstage and output transformers used.

this network, resulting in about 20V available for biasing. Connections to the network result in the output stage being biased for Class-AB operation. Bias for the driver stage is tapped off at a lower voltage resulting in Class-A.

When the output stage is driven hard, the change in bias results in a shift of the driver's operating point. This will partially compensate for output stage shift. A good description of this technique is covered in a reprint of the *1937 Sylvania Technical Manual*[3]. You will find it on page 113 under Type 42 Power Amplifier.

Finally, the input amplifier is biased off the bottom end of the resistive network. The capacitor C3 prevents instability which would result from interstage feedback in the bias network.

Resistors R8 and R9 have been included to help avoid parasitic oscillations and reception of your friendly local radio station. They are not used on the power tube grids since they need to draw considerable current on program peaks.

Since this amplifier needs to run in Class-AB2, I was curious as to how much grid current would flow in the output tube grids. I connected a 10Ω resistor (R13) in the grid return leads so that the grid current could be monitored at Test Point One (TP1). Refer to the resulting double oscilloscope trace in *Fig. 2*.

The 1kHz output signal is set to maximum, about 4.5W in the ultralinear connection. Scaling on the left-hand side refers to the output. A X10 probe was used. Scaling on the right-hand side refers to the resulting grid current. In this instance I used a X1 probe. The grid current peaks are about 1.5mA.

No adjustments are provided to set the amplifier for minimum distortion. However, you may want to try balancing the output stage by simply switching the 33s. I was surprised to find a worthwhile improvement in distortion readings at lower levels by using this technique. You will need something (distortion meter) to measure the results. My results are shown as part of *Table 1*.

THE POWER SUPPLY

Power requirements are modest, so that a relatively simple power supply will do (*Fig. 3*). The amplifier needs a total of about 200V in order to deliver full power. The plate circuit runs on 180V, while the biasing network uses the remaining 20V.

Voltage is kept down by using a rather small value (8μF) cap at input to the filter network. This also keeps the RMS current in the transformer down to prevent excess heating. You will need DC for the filaments of this tube series. The LM317 does a good job of filtering ripple at the output of the bridge rectifier. It also provides the 3.8V needed to run the soft-start circuit.

During development of the amplifier I was concerned with the effect the turn-on transient would have on filaments in these relatively fragile tubes. When I switched a 33 directly to a 2V, 25ah Gates Cell, I measured turn-on transients of more than 1A. After about one second the current settled down to the specified 0.26A.

Ordinary VOMs and DMMs are not very accurate for the measurement of small resistances. That is partly because of lead and contact resistance. Accurate measurement of small resistances are best made by the four-terminal method. A constant current is applied to the unknown R. Both current and voltage are measured on the leads of the R and then Ohm's law is applied.

Using this technique, I found the 33

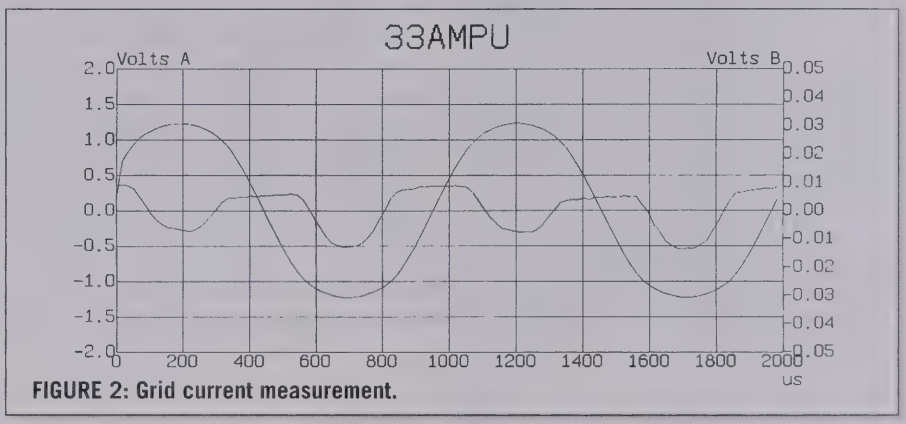


FIGURE 2: Grid current measurement.

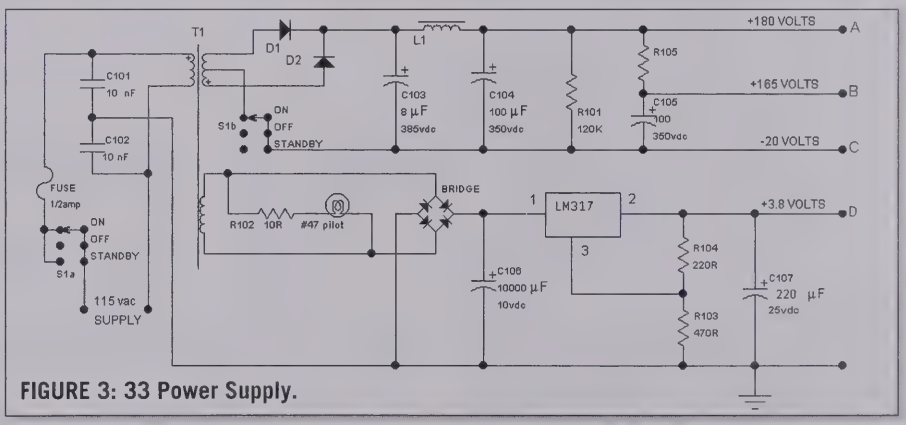


FIGURE 3: 33 Power Supply.

TABLE 2
TUBE CHARACTERISTICS

33 PENTODE AND 1B5/25S ARE PUBLISHED.
33 UL AND TRIODE SPECS ARE MEASURED.

	33			1B5/25S
	PENTODE	UL	TRIODE	
Plate voltage	180	180	170	135
Screen voltage	180	180	———	———
Grid voltage	–18	–20	–16.5	–3
Plate resistance	55k	7.9k	3.7k	35k
Mutual conductance	1.7mA/V	1.33mA/V	1.33mA/V	0.575mA/V
Amplification factor	93	10	5	20

heater cold resistance to be 1.8Ω. That result is consistent with the greater than 1A turn-on transients just measured. By inserting a small resistance in series with each of the heater leads, the turn-on transient is greatly reduced. For the 33s I used 6.8Ω, made by paralleling a 10Ω, 2W resistor with a 22Ω, ½W resistor.

Resistance in the 33 heater circuit now totals 8.6Ω. The turn-on transient now measured 0.44A. Again, the heater current drops to the specified 0.26A in about one second. A 30Ω, 2W resistor performs the same function for the 1B5/25S heater.

TABLE 3
PARTS LIST

C1	0.22µF 400V DC
C2	1.0µF 400V DC
C3	2200µF 25V DC
C101, C102	10nF, Mallory UN102M
C103	8µF 385V DC
C104, C105	100µF 350V DC
C106	10000µF 10V DC
C107	220µF 25V DC
R1	470k ½W
R2	100k 2W
R3	470k 2W
R4, R12	30Ω, 2W
R5, R6, R7	10Ω, 2W in parallel with 22Ω, ½W
R8, R9	1k ½W
R10	220Ω, 2W
R11	47Ω, 2W
R13	10Ω, ½W
R101	120k 2W
R102	10Ω, 2W
R103	470Ω, ½W
R104	220Ω, ½W
R105	270Ω, 2W
R106	150Ω, 2W
T1	Hammond 269EX 190-0-190 @ 65mA DC and 6.3V AC @ 2.5A
T2	Hammond 1609 output, 10k plate to plate 4, 8 and 16Ω secondary taps
T3	Hammond H300759 6k plate to 9.6k center-tapped grid to grid
V1	1B5/25S
V2, V3, V4	33
D1, D2	FR107 fast recovery, AE p/n P-QFR107
L1	Hammond 156L 5H, 75mA
Bridge Rectifier	BR-34, AE p/n P-QBR-34
S1	DPDT center off switch

LM317 regulator
#47 pilot and holder, AE p/n P-L114
Fuse ½A and holder, AE p/n S-H258
Aluminum chassis 8″ × 16″ × 2″ Hammond 1444-26. If still available AE p/n P-H120
Aluminum bottom plate 8″ × 16″ Hammond 1434-26
5 pin sockets, AE p/n P-ST5-216, need three
6 pin socket, AE p/n P-ST6-207M, need one
Terminal strips

AE p/n	lugs	quan
P-0201H	2	1
P-0301H	3	3
P-0401H	4	1
P-0501H	5	2
P-0701H	7	2
P-0901H	9	5
S-H317	6 screws	1

Double phono jack AE p/n S-H310
6′ line cord AE p/n S-W105
Rubber grommets AE p/n P-G005, need five
Rubber feet AE p/n P-H253, need four
Assorted machine screws, nuts, and washers
AE indicates Antique Electronics
Some parts are available at Radio Shack

CONSTRUCTION

The chassis I used for this project may appear to be large for the number and complexity of the components installed. That is because my version of the amplifier was built for development purposes. I wanted lots of room to try a number of ideas which usually come to mind during one of these exercises. I will describe two of these at the end of this article.

While reading articles devoted to the efforts of amateur constructors, I've made some interesting observations. I hope my comments will help you build a successful project.

You should spend 90% of your time making sure that what is under the chassis is well done. Cosmetic appearance of the exterior will have little effect on the sound that you hear coming from your loudspeakers.

Attention to detail under the chassis—and, in particular, to soldering—will make the difference between success and failure. A poor solder joint can make a very good semiconductor. I am aware of this from personal experience. A sine wave applied on one side shows up as a half-wave rectified waveform on the other. It does awful things to your sound.

Terminal strips are one of the best-kept secrets of a successful project. They are inexpensive and will turn a rat's nest into a work of art.

Most of the building and testing of your project requires access to the underside of the chassis. Use a simple wooden frame attached to each end of your chassis to lift it well off the work bench while inverted (*Photo 1*). This will help in avoiding damage to the tubes and scratching the finish on transformers and chokes. If you would like, leave them on. They make great handles. I use wood trim, available at your local lumber store.

Mount a 1½″ × 6-32 machine screw so that it protrudes from the back of the chassis. This will be very handy as a ground connection when you are testing any box of electronics. DIYers always seem to need far more ground connections when testing than there is space for. Problem solved.

Buy your fastening hardware such as screws, nuts, and washers in quantity. They are cheap at the large building-supply stores. This will help you avoid the frustration caused by running out when you need them most.

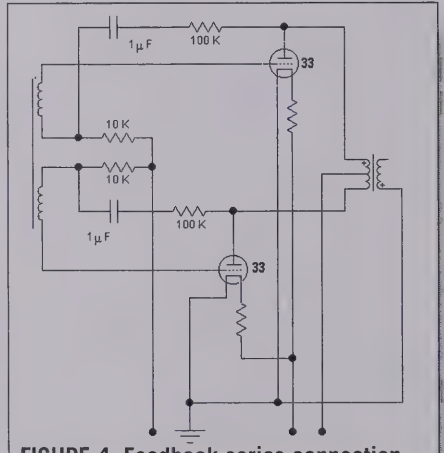


FIGURE 4: Feedback series connection.

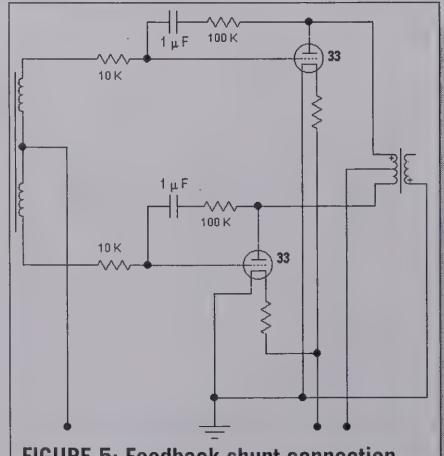


FIGURE 5: Feedback shunt connection.

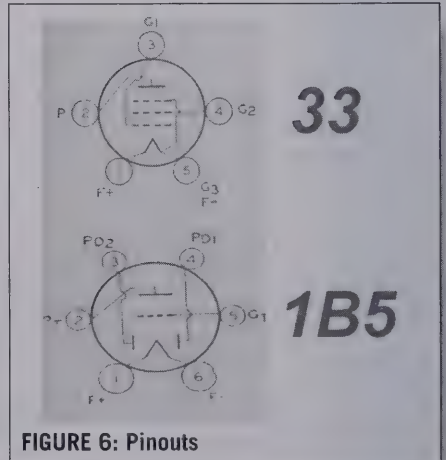


FIGURE 6: Pinouts

You should expect the unexpected. It happens all the time even to those of us who think we know what we are doing.

MORE

There are several ways you can connect feedback to a single stage. The ultralinear connection is one of the most important and it is used in this amplifier to advantage.

I was interested in trying another method which shows up in some 1930s radios (*Figs. 4* and *5*). You make a direct connection through an RC network between the plate and control grid of each tube. The resulting stage gain is controlled by the ratio of the feedback resistors. In each of the examples that would be ten. Both examples are unconditionally stable.

In a circuit using pentodes, the gain is normally limited by the load impedance. Gain for a pentode is usually calculated as transconductance times load impedance. That works out to about ten for the 33 when normally loaded. This is typical for pentodes and beam tubes.

However, gain can become very high when connected to a complex load such as a loudspeaker. At the loudspeaker's resonant peak(s), gain could go up to five or ten times the nominal. The result is usually poor sound. The amplifier has little control over the loudspeaker. You will have lots of overhang. The performance is typical of what some call the pentode sound.

You can control this condition by using one of the circuits illustrated. Gain is effectively controlled by the feedback resistors. The capacitor isolates the DC voltages on the plate and grid.

Figure 4 is the series connection of this feedback. The feedback voltage appearing at the junction of the 10k resistor, 1µF cap, and interstage transformer secondary is in series with the voltage in the interstage secondary.

Figure 5 is the shunt connection of the feedback. The feedback voltage in this mode is in opposition to that in the interstage secondary. This connection is effective in loading the interstage secondary to reduce ringing. The ringing results from stray capacities and leakage inductance in the transformer.

I did not use either of these connections in the final amplifier. The output stage needs to operate in the Class-AB2 mode in order to deliver full power. The RC feedback networks would prevent necessary grid current from flowing. ❖

EQUIPMENT USED IN THE DEVELOPMENT OF AMPLIFIER

HP 200CD Oscillator

HP 302A Wave Analyzer

GW GAG-810 Oscillator

Rohde & Schwarz BOL 4 Trace 100MHz Scope

Radio Shack 22-168A DMM

Sanwa AX 303-TR Analogue Multimeter

PicoScope ADC-100 Virtual Instrument

Electronic Workbench Software (available from Interactive Image Technologies, 801-111 Peter St, Toronto, ON, M5V 2H1, 800-263-5552, www.interactiv.com)

REFERENCES

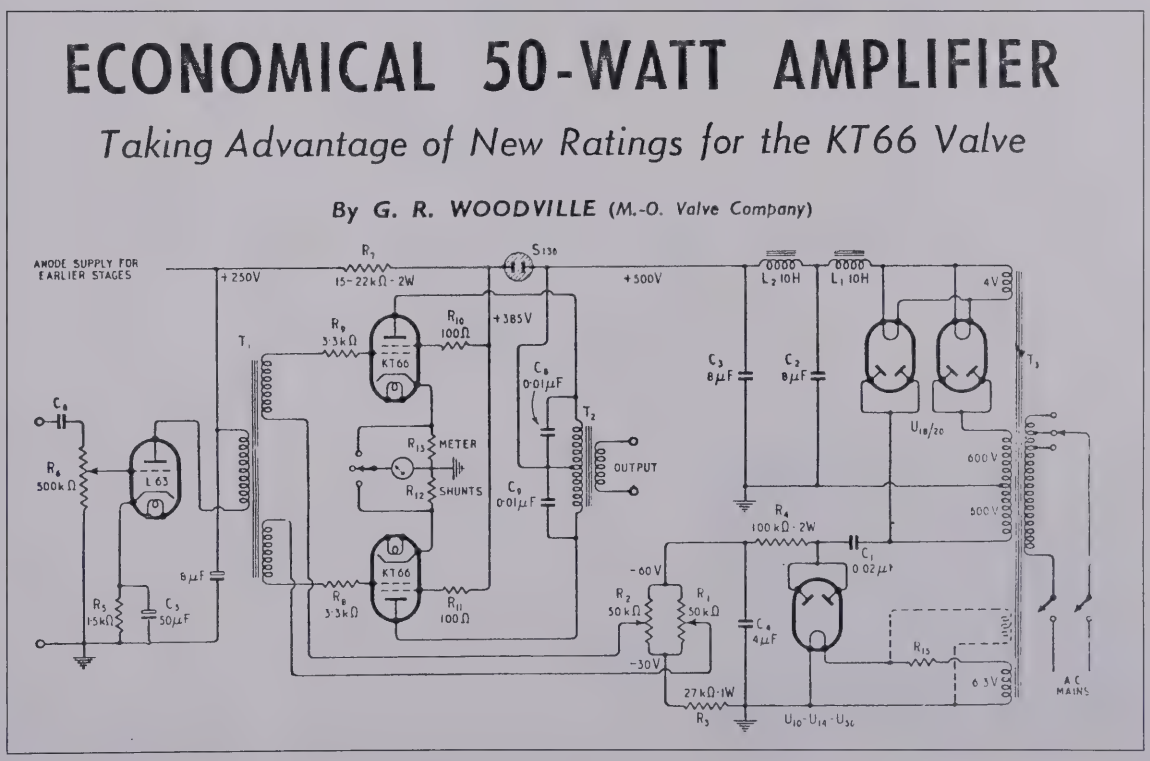
1. *Audio Measurements*, Norman Crowhurst (available from Old Colony Sound Lab, 603-924-6371, FAX 603-924-9467, custserv@audioXpress.com)

2. "Twin Coupled Amplifiers," Norman Crowhurst, *Radio Electronics*, Nov. 1957; Oct. 1960; June 1960.

3. 1937 *Sylvania Technical Manual* (available from Antique Electronic Supply, 6221 S. Maple Ave., Tempe, AZ 85283, 800-706-6789, www.tubesandmore.com)

Classic Circuitry

Dyna 120



Courtesy of: Hilary Paprocki, Rochester, N.Y.

FIGURE 1: Dynaco 120W amplifier using Dynaco A-451 transformer.

Design a 6528 SE Amp

Although not much is known about the 6528 tube, it proved to be quite satisfactory for this single-ended design.

By Ignatius Chen

When I first saw the 6528 tube at a flea market, I had a strong sense that it would be a good single-ended amp power-tube candidate, so I decided to build such a unit *(Photo 1)*. At a glance, the shape of this bottle is very similar to the GE KT88; inside the glass there are twin rug black plates, which look much stiffer than the plate of the 6080 (6AS7).

When I returned home, I realized there was not much information available for this tube; the only data I could obtain was its maximum and nominal voltage and current from the GE data book.

I have been looking for its characteristic curve in many places, but apparently it is not available. Finally, I must determine how to model the curve, since it is important in designing to show where the best working point is, and what voltage swing is required.

PHOTO 1: 6528 SE amp.

PLATE DISSIPATION CURVE

In *Table 1*, you see there is only one maximum plate-dissipation curve and one working point (Vp = 100V, Ip = 185mA, bias = –4V) that I can plot. Plate dissipation is the product of plate voltage and plate current, with 30W as its maximum value. A combination of Vp and Ip is a border where no grid-voltage swing is allowed to cross this line unless in transient time; but where is the best working point? This point should be located at about the middle of the tube-characteristic curve to ensure linear signal amplification.

With the plate voltage (x-axis) and plate current (y-axis), together with the plate dissipation curve, I then estimate that 200V is the best working plate voltage. If you carefully study the power-tube plate-characteristic curve, you will find that the best working voltage will be at about the tangent point of the curve.

ABOUT THE AUTHOR

Ignatius Chen, age 30, is a civil/structural engineer and graduated from Parahyangan Catholic University in Bandung. He is director of PT Duta Akustika, an engineering consulting firm specializing in hi-fi/pro audio, structural design, and ace engineering. He has loved music and electronics since being a student. Besides reading classic Chinese novels, growing cactus, and collecting rabbits, he also enjoys writing about tubes for Indonesia Audio Video magazine and Hongkong audiophile. He can be reached at

μ, GM, AND R_P

These three interrelated parameters best define the tube characteristic comprehensively (those interested in basic tube theory can refer to Rozenblit's *Beginner's Guide To Tube Audio Design*, available from Old Colony Sound Lab, PO Box 876, Peterborough, NH 03458, 888-924-9465, www.audioXpress.com). The three parameters are related by

$$Gm = \frac{\mu}{R_P}$$

R_P is dynamic plate resistance, defined as the ratio of a small change of plate voltage to a small change of plate current, where grid voltage is held constant. If you know R_P for a certain Vp and Ip, then you can draw the first modeled tube curve, passing through the Vp = 100V and Ip = 185mA point (point A) with about a 1:4 slope:

$$R_P = \frac{\Delta Vp}{\Delta Ip} = 245.$$

Gm is the tube's transconductance, defined as the ratio of a small change of plate current (ΔIp) to a small change of grid voltage (ΔVg), where plate voltage is held constant:

$$Gm = \frac{\Delta Ip}{\Delta Vg}; \text{Vp constant}.$$

A larger Gm means that the tube is sensitive to an increase in plate currents. A small change of grid voltage will cause

TABLE 1

TUBE TYPE	CLASSIFICATION OF CONSTRUCTION	BASE CONNECTION	FILAMENT VOLTAGE	FILAMENT CURRENT	MAXIMUM PLATE VOLTS/ WATT	CAPACITANCE IN PF INPUT	OUTPUT	GRID PLATE
6528	Twin triode	8BD	6.3V	5A	400/30	17.8	2.9	23.8

NOMINAL WORKING POINT PLATE VOLTS	NEGATIVE GRID VOLTAGE	PLATE CURRENT (MA)	R_P (OHMS)	GM (µMHOS)	µ
100	4	185	245	37.000	9

a large amount of increase in plate current; i.e., with a grid-voltage swing from –4V to –2V and –6V, the plate current will vary 74mA (from 111mA to 259mA). From this initial information, you can draw three modeled tube-characteristic curves (line). Now, you can draw a set of lines (in an actual plate curve, the linear part is only at the middle part of the curve) at 2V intervals with the same line-to-line distance and slope.

Figure 1 shows a completed modeled plate curve (line). 200V (Vp) looks like a reasonable working point with bias 17V. You can roughly see that a 30V grid-voltage swing is possible for driving this tube. With this starting point, I tried to design a single ended amp to see whether my assumption was correct.

FINAL STAGE

With bias 17V and Vp 217V (to cathode it is 200V), the estimated Ip would be 125mA according to the modeled plate curve. The output transformer is a matching device. You can use a Hammond P-T 1640 SE (25W, 12.5kΩ primary impedance, 200mA). By turns ratio it is true that the final-stage tube will see a 1.25k impedance if loaded with an 8Ω speaker. But since the transferred audio signal varies in wideband, (i.e., from 40Hz tuba bass to 4kHz piccolo), in my opinion the slope of the load line will vary also in a range from tg α = 0.265mA/V to tg α = 0.00265mA/V. The explanation is as follows.

To the AC signal being transferred, the primary coil of an OPT inductive reactance X_L is equal to 2πfL; if L = 15H then X_L = 94.25 f. For f = 40Hz, X_L = 3770Ω, and for f = 4000Hz, X_L = 377kΩ. With Vp = 200V, the slope of the load line will be 0.265mA/V and 0.00265mA/V, respectively.

$$\left(\text{tg}\,\alpha_1 = \frac{200/3770 \times 1000}{200}\,\text{mA/V and} \right.$$

$$\left. \text{tg}\,\alpha_2 = \frac{200/377000 \times 1000}{200}\,\text{mA/V} \right)$$

Now, it is clear that the voltage swing for a small-distortion output will most likely be between –2V and –34V, or about 36V pp. With this assumption I continued to design the driver stage.

DRIVER STAGE

Because of the small voltage-swing requirement (+36V pp), and taking into consideration losses of signal during transfer between stages, I chose 12AT7 as the driver tube. This popular twin triode has a mu of approximately 60. I did not choose 12AX7, since its mu is too high, and conversely the mu of 12AU7 is too low. I can't find the plate curve of 12AT7; the only information I can find is its nominal Class-A working point, issued by GE.

Without a cathode-bypass resistor, the gain of this stage will be

$$\text{gain} = \frac{\mu RL}{Rp + RL + RK(\mu + 1)} = 29\ ,$$

where µ = 60, RL = 30k, R_p = 15k, RK = 270Ω. The amplification capability of this tube has been reduced by almost 50% due to local negative feedback between grid and cathode. The next step is to determine the interstage losses to see how much signal can be delivered to the grid of the 6528.

Use the formula ,

$$V_{out} = \frac{E\,Z_{in}}{Z_{out} + Z_{in}}\ ,$$

where E = driver output signal voltage,

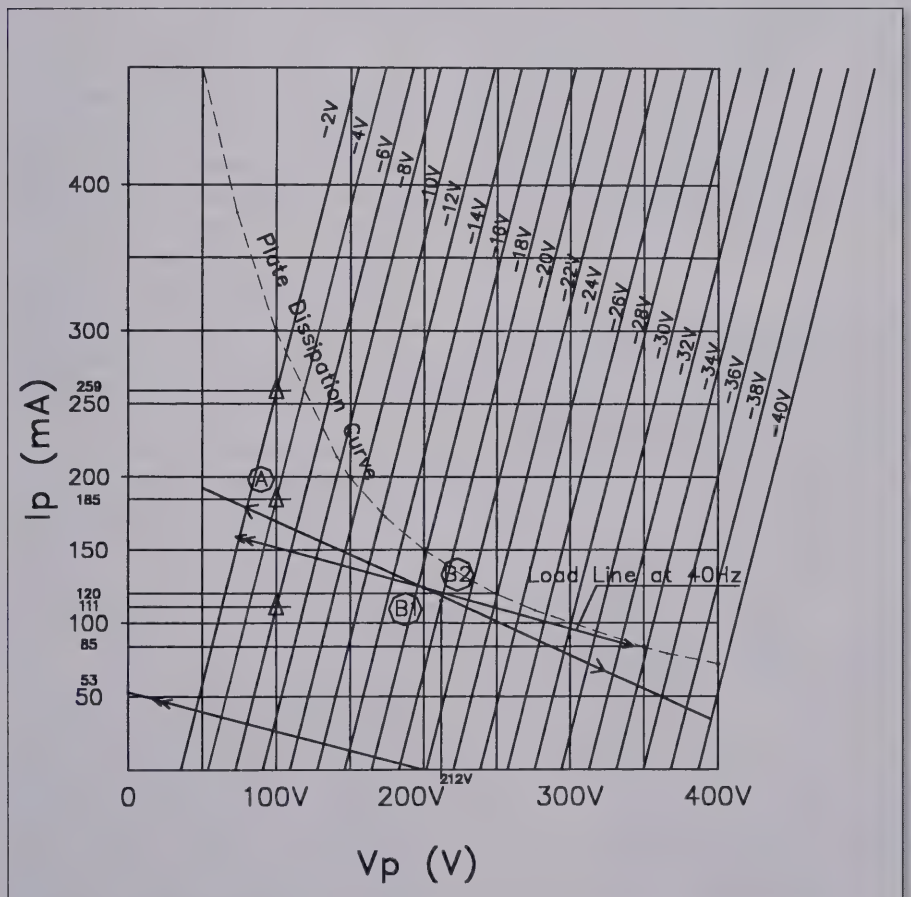


FIGURE 1: 6528 modeled plate curve. G-1814-1

Z_{in} = 6528 input impedance, Z_{out} = 12AT7 output impedance, and V_{out} = transferred signal voltage. It is clear that for best signal transferring, the Z_{in} should be as large as possible, and the Z_{out} should be as small as possible.

Z_{in} of the final stage can be calculated as follows: Cgp' = (gain+1)Cgp. With a signal frequency of 20kHz, the gain of this final stage will be approximately nine.

$$\left(\text{Gain} = \frac{\mu RL}{R_P + RL}; \text{where } RL = 2\pi fL\right)$$

Cgp' = (9 + 1)23.8 = 238pF
C_{in} = Cgp + Cgk = 255.8pF

$$Zc_{in} = \frac{1\times10^{12}}{6.28.20000\ 255.8} = 31k\Omega\ .$$

Combining this figure with Rg (500k) yields Z_{in} = 29k. The Z_{out} is the output impedance of the driver tube, which is the parallel value of RP and RL.

$$Zout = \frac{30\times15}{30+15} = 10k\ ;$$

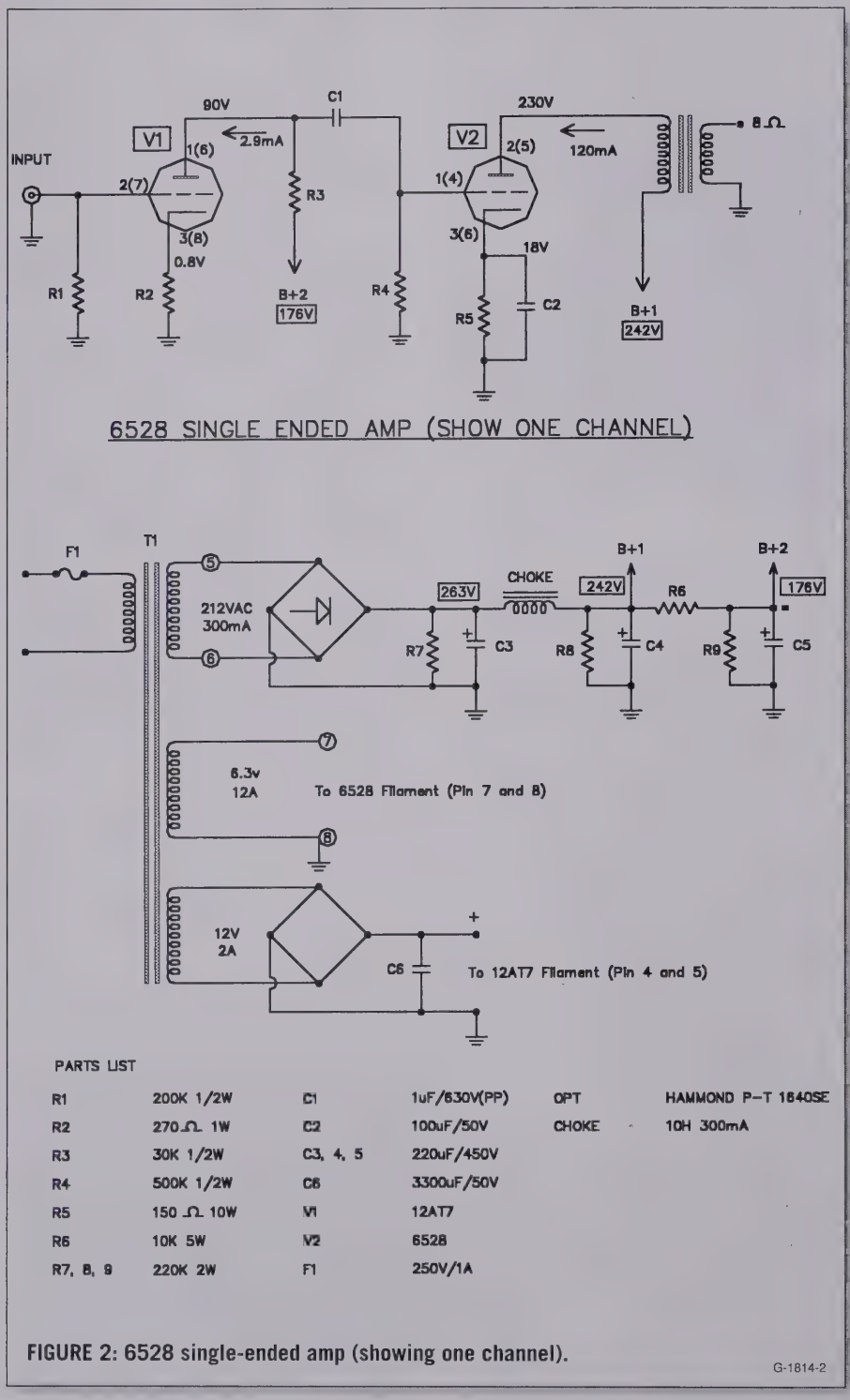
therefore,

$$Vout = E\frac{29}{29+10} = 0.743E\ ,$$

or the transferred signal at 20kHz is about 75% of the signal produced by the driver stage. How about the low frequency signal? The lower the frequency, the higher the Zc_{in}, and this will give a higher signal-transfer rate result.

With a 1V (pp) input signal, the final stage will produce roughly 196V pp. If the OPT turns ratio is 19:1 (8Ω), the voltage at the secondary winding will be 10.3V pp, or 7.3V RMS, so the power produced is approximately

$$P = \frac{V^2}{R} = \frac{7.3^2}{8} = 6.7W\ .$$



PARTS LIST

R1	200K 1/2W	C1	1uF/630V(PP)	OPT	HAMMOND P-T 1640SE
R2	270Ω 1W	C2	100uF/50V	CHOKE	10H 300mA
R3	30K 1/2W	C3, 4, 5	220uF/450V		
R4	500K 1/2W	C6	3300uF/50V		
R5	150Ω 10W	V1	12AT7		
R6	10K 5W	V2	6528		
R7, 8, 9	220K 2W	F1	250V/1A		

FIGURE 2: 6528 single-ended amp (showing one channel).

G-1814-2

CONSTRUCTION

Upon completing the design, I collected the parts for constructing this project. Transformer supplies were not a problem, since I used to collect them. I salvaged T1 from some old testing equipment. With this transformer, the B+1 voltage is a bit higher than the designed working point. With 18V bias (the B2 point on the curve), which is very close to B1, I concluded that the modeled curve could be acceptable. *Figure 2* shows the amp circuit, along with parts list.

The choke (NOS from military stock product) looks as though designed for a 3000V high-voltage power supply: 10H, 300mA. All high-wattage resistors were purchased from a flea market. They are all still in service, even at 50 years of age.

The suitable OPT is Hammond P-T 1640SE (primary 1.25k, maximum DC 200mA) or UBT-1 (1.6k, 8H at 160mA maximum). As I have shown, the R_P of the 6528 is only 245Ω, which is about the R_P of three 300Bs in parallel. For readers who prefer to wind their own, the *Practical Transformer Design Handbook* is a good guide. ❖

A 300B Parallel Single-Ended Amp

This project is designed to achieve maximum performance, and two different versions allow you to find the best sound for your system.

By Andrea Ciuffoli

The idea behind this project was to produce a reference amplifier to compare new projects. Of course, the reference of an audio system or component should be the live sound of an instrument or orchestra, but my little house has no room to accommodate some musician.

When I optimize my amplifiers, I search for what I think should be the better sound: no coloration. When I am quite sure I have achieved my goal, I invite some of my friends to verify.

THE 300B

Some may disagree, but the 300B is considered by most people—and especially the Japanese—to be the best output tube. People love its sound.

The 300B reproduces the middle frequencies with a very natural sound. If you are looking for a 300B, you'll find many manufacturers offer a wide range of prices. For this project I chose the Svetlana 300B, which is a close duplicate of the original Western Electric 300B.

The Svetlana 300B uses ultra-pure carbonized nickel plate material and a proprietary oxide coating on the filament to achieve Western Electric-like performance. The filament is center-tapped to ensure low hum. The Svetlana 300B is manufactured in Russia at their factory in St. Petersburg. I believe the strict manufacturing and quality controls at the Svetlana plant assure functionality and sound as good as Western Electric-manufactured products.

My idea was to produce an amplifier without any interstage capacitor or resistors in the signal path, because either can produce a colored sound if they are not top quality. After many tests I suggest you use only Caddock resistors and Jensen copper film for capacitors of paper or in oil. *Photos 1-3* show the exterior and interior of the completed unit.

The output stage is a parallel configuration to increase the output power; a

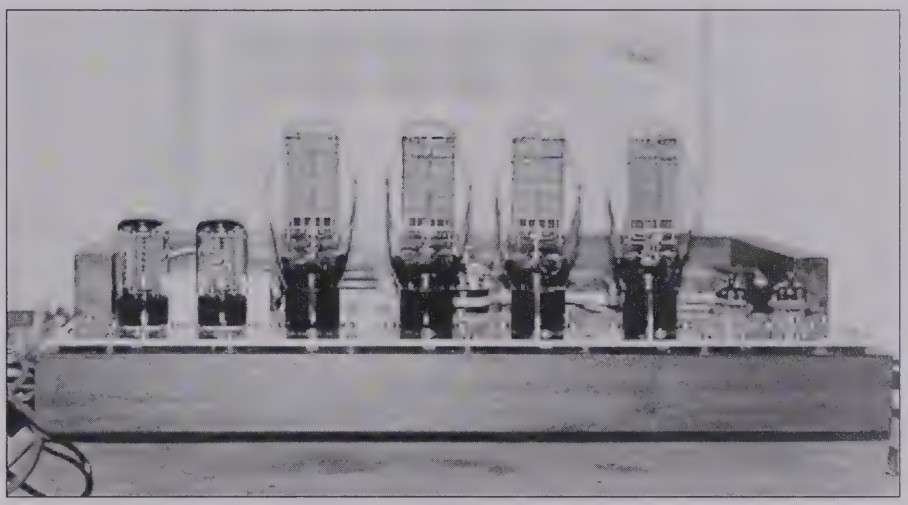


PHOTO 1: Front view of amp.

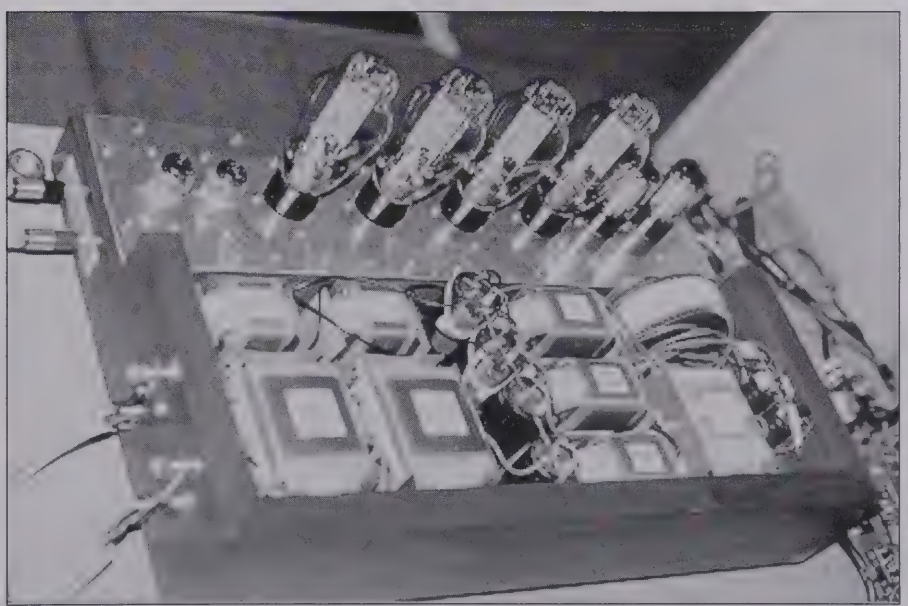


PHOTO 2: Overhead view of amp from back.

ABOUT THE AUTHOR

Andrea Ciuffoli, who is 34 years old and lives in Rome, first became interested in audio electronics over ten years ago, specializing in vacuum tube amplifiers for the past seven years. Ciuffoli manages Internet E-Commerce services for a major telecommunications company (www.saritel.it). For details of Andrea Ciuffoli's projects, visit www.audiodesignguide.com or e-mail audiodesign@tin.it.

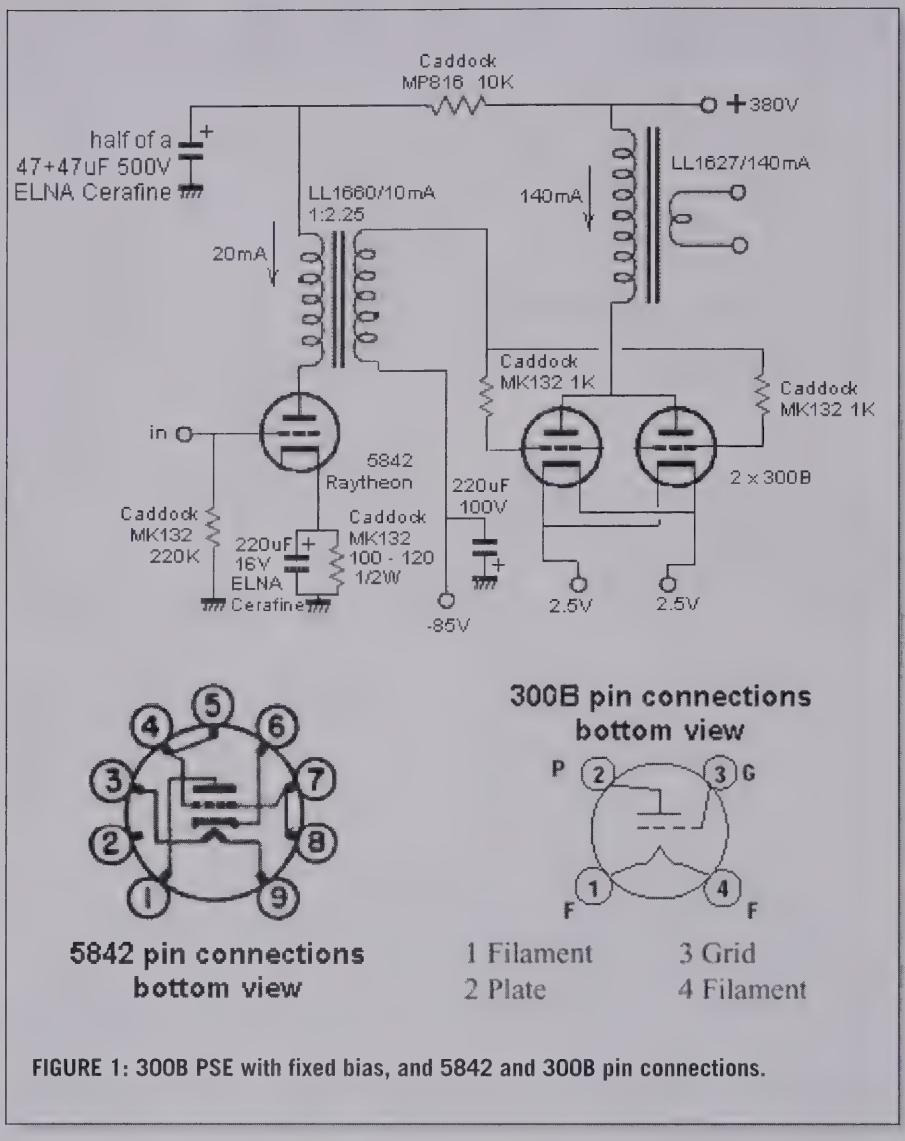


FIGURE 1: 300B PSE with fixed bias, and 5842 and 300B pin connections.

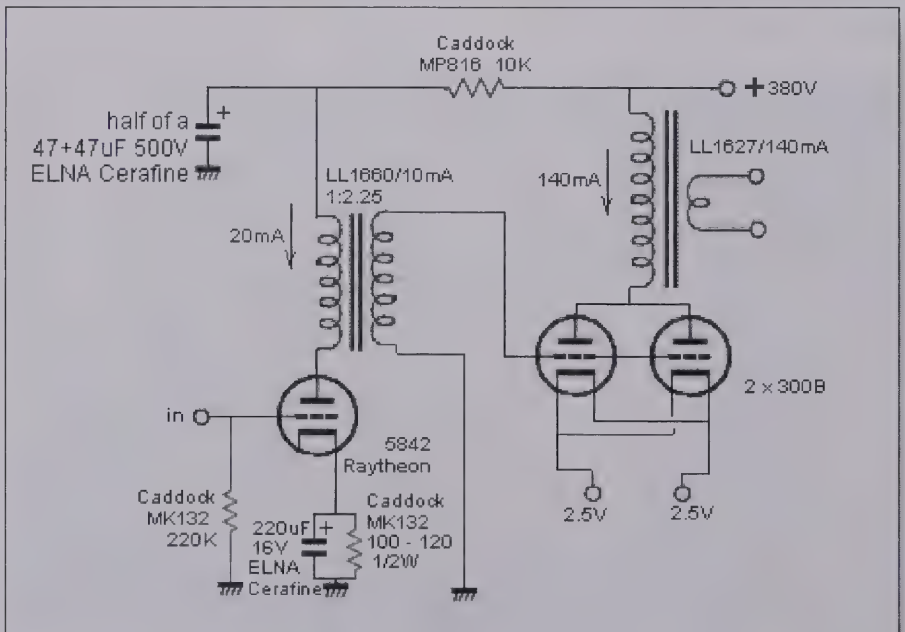


FIGURE 2: 300B PSE with automatic bias.

single 300B can deliver 9W, but you get the best sound from this tube when it is used to produce only 6 or 7W. A power of 9 or 6W is a very low power level if your loudspeakers have a medium efficiency (about 89–90dB).

The way to get more power from a 300B is either in parallel or push-pull configuration. If you are making a reference amp, a push-pull arrangement is unacceptable because the distortion spectrum decay will never be natural. The parallel configuration is the best answer.

PARTS SELECTION

I made many tests for the input stage before finding the best result with the Raytheon 5842. I did not consider either the SRPP (totem pole) or mu-follower in my design because with these the distortion spectrum decay must be analyzed with great care to be sure that there are no strange effects. The single-ended topology is natural.

Using the 5842 and an interstage transformer with a turns ratio of about 1:2, you can produce an amplifier with only two stages. Any transformer in a tube amplifier, especially the transformer in the signal path, should be of the highest quality your budget can support.

I use all Lundahl products, which provide a very high quality performance as well as very clear datasheets with all the parameters to enable the designer to achieve a precise design. Lundahl can also gap the single-ended transformers to your requirements to optimize the inductance for the desired bias current. Lundahl is one of the world's leading manufacturers of audio transformers used in many professional recording studios and radio stations. They have extensive experience and all their products use a custom audio C-core.

In designing a reference top performance amplifier, consider only vacuum tube rectifiers. Given the high current required by parallel connection of two 300Bs per channel, I have used the king of the vacuum diodes: the Mullard GZ34/5AR4. You should not have a problem finding the other tubes, but the GZ34 is not plentiful and the price is very high for the genuine article, somewhere between $25–$30.

In most designs the cathode of the 300B is connected to a high power trimmer to manually find the best point to reduce the hum. With the Svetlana 300B this is not necessary because the filament is center-tapped and you only need to be sure that the transformer winding for the 300B filaments is symmetric (3.15V-0-3.15V). Amp connections are shown in *Photos 4* and *5*.

I believe there are few good choices

LISTENER IMPRESSIONS BY FRANCESCO PINTAVALLE

Due to the usage of a fully transformer-coupled system, the amplifier seems to disappear, especially when set up with a fixed bias for the power tubes.

The soundstage is really impressive, stable, clean, open, and wide. Instruments are perfectly positioned in the acoustic scene. The depth of the musical event, as well as its elevation, is really stunning. I can "see" the natural dimensions for each instrument.

The power is more than what is required for a good output level. In particular, with complex musical events such as orchestras, there are no compression effects at any level.

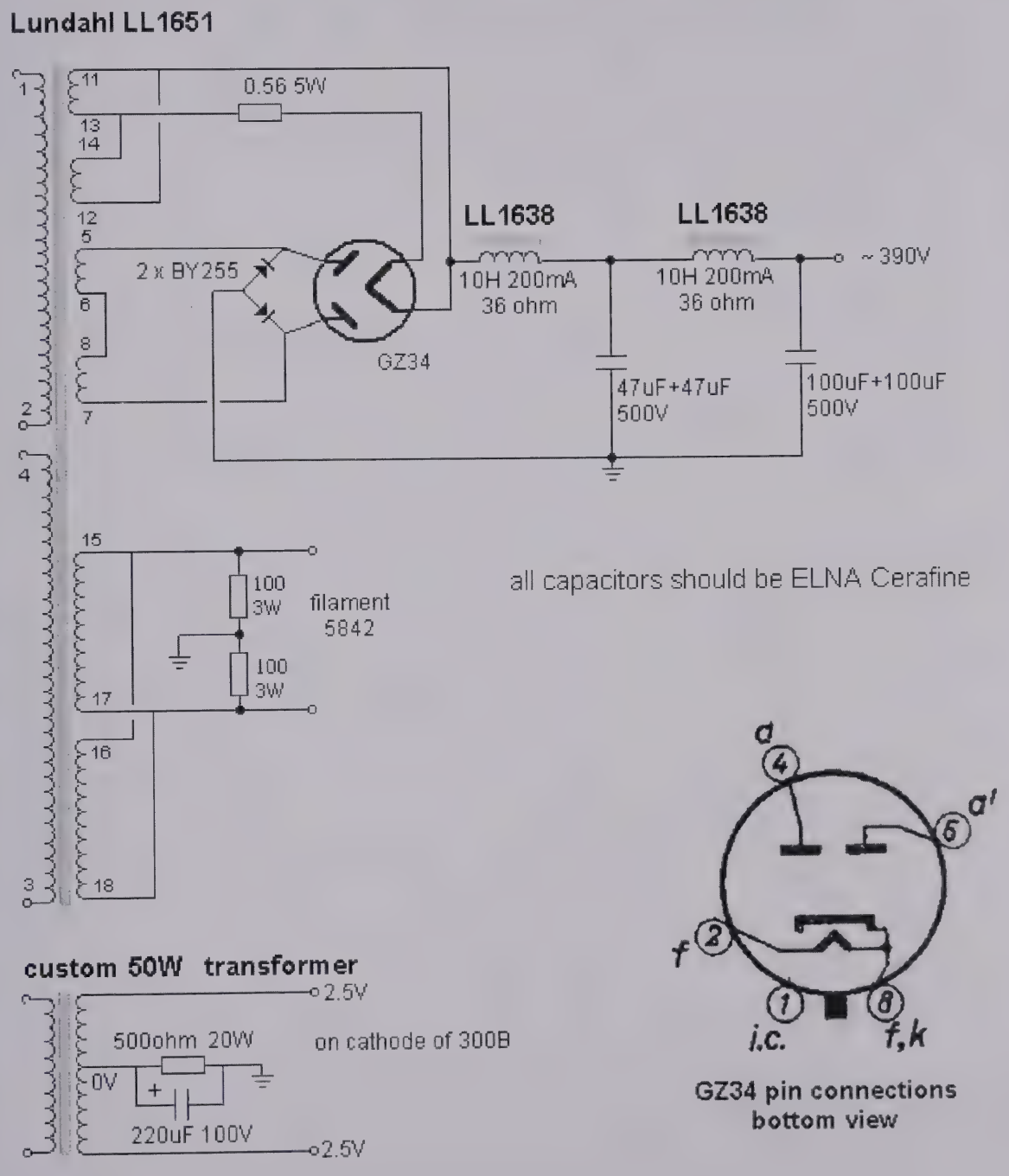


FIGURE 3: Power supply for the 300B PSE (Parallel Single Ended) with automatic bias (one channel only), and GZ34 pin connections.

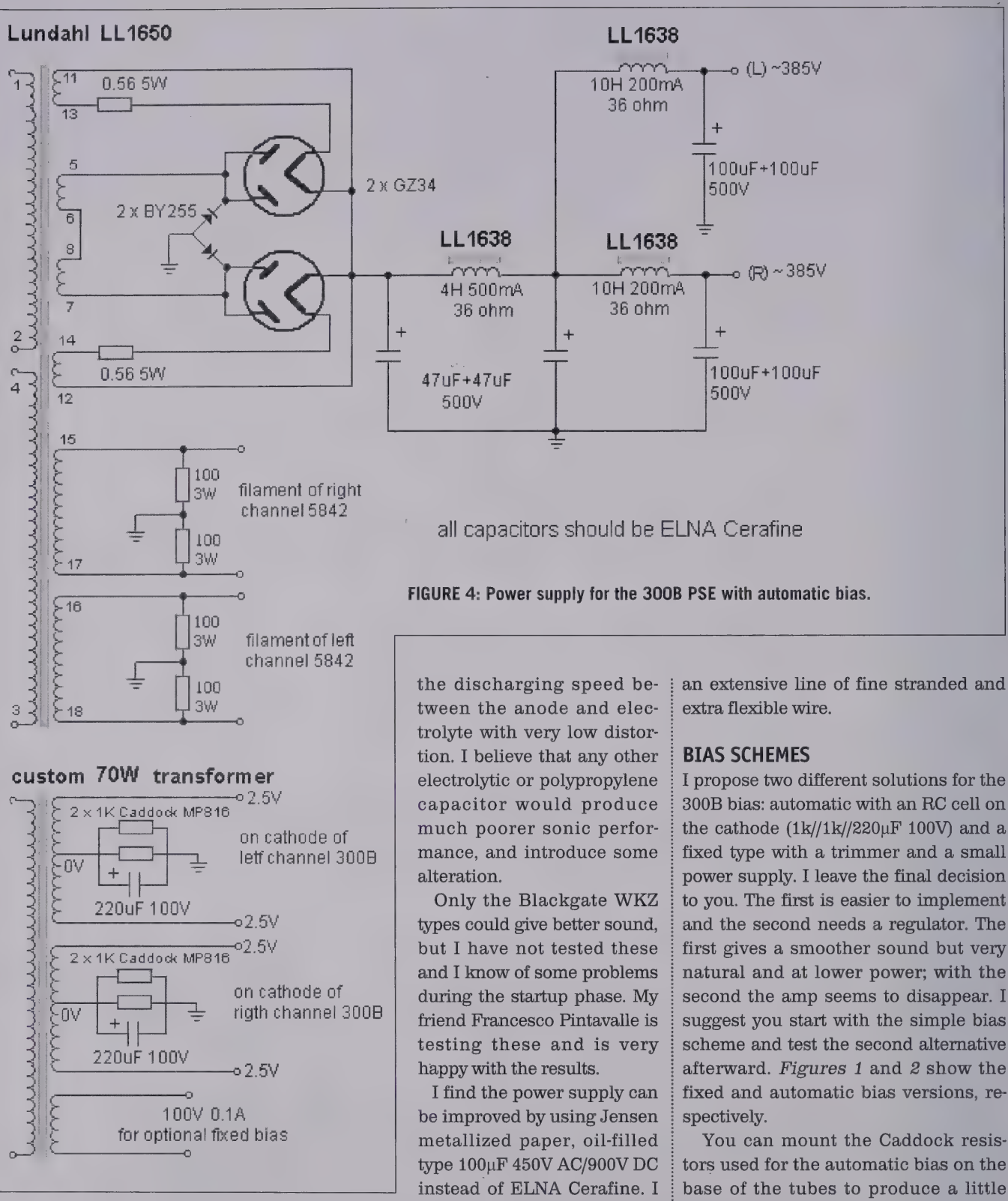


FIGURE 4: Power supply for the 300B PSE with automatic bias.

for the passive components types: Caddock resistor (MK132 0.75W or MP816 16W) and ELNA Cerafine capacitors for the cathode and power supply. The ELNA Cerafine capacitors contain super-fine ceramic particles which, through chemical reaction, improve the discharging speed between the anode and electrolyte with very low distortion. I believe that any other electrolytic or polypropylene capacitor would produce much poorer sonic performance, and introduce some alteration.

Only the Blackgate WKZ types could give better sound, but I have not tested these and I know of some problems during the startup phase. My friend Francesco Pintavalle is testing these and is very happy with the results.

I find the power supply can be improved by using Jensen metallized paper, oil-filled type 100µF 450V AC/900V DC instead of ELNA Cerafine. I am currently testing these on another amplifier and the result is excellent.

In choosing wire, avoid the teflon. I use only stranded tinned copper wire with PVC insulation. You may buy a very good quality stranded tinned copper wire from E-Z-Hook, which carries an extensive line of fine stranded and extra flexible wire.

BIAS SCHEMES

I propose two different solutions for the 300B bias: automatic with an RC cell on the cathode (1k//1k//220µF 100V) and a fixed type with a trimmer and a small power supply. I leave the final decision to you. The first is easier to implement and the second needs a regulator. The first gives a smoother sound but very natural and at lower power; with the second the amp seems to disappear. I suggest you start with the simple bias scheme and test the second alternative afterward. *Figures 1* and *2* show the fixed and automatic bias versions, respectively.

You can mount the Caddock resistors used for the automatic bias on the base of the tubes to produce a little heatsink. If you use the second bias method (fixed), you must set the trimmer to produce –85V on the grid of the 300B before inserting the tube into the socket. The 300B grid resistors (1k MP816 Caddock) are necessary only for the fixed bias configuration.

In any case, you should ask for 300Bs

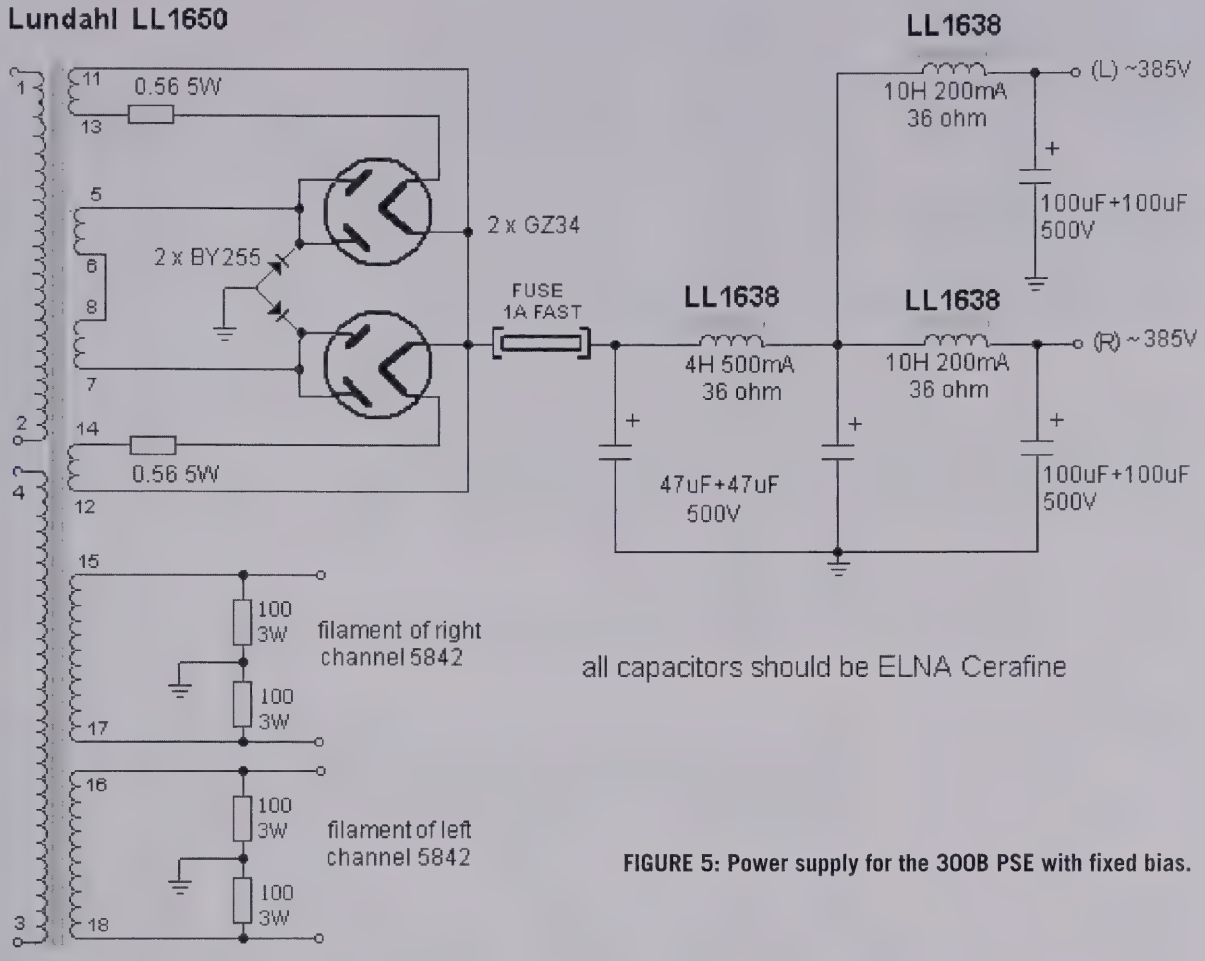
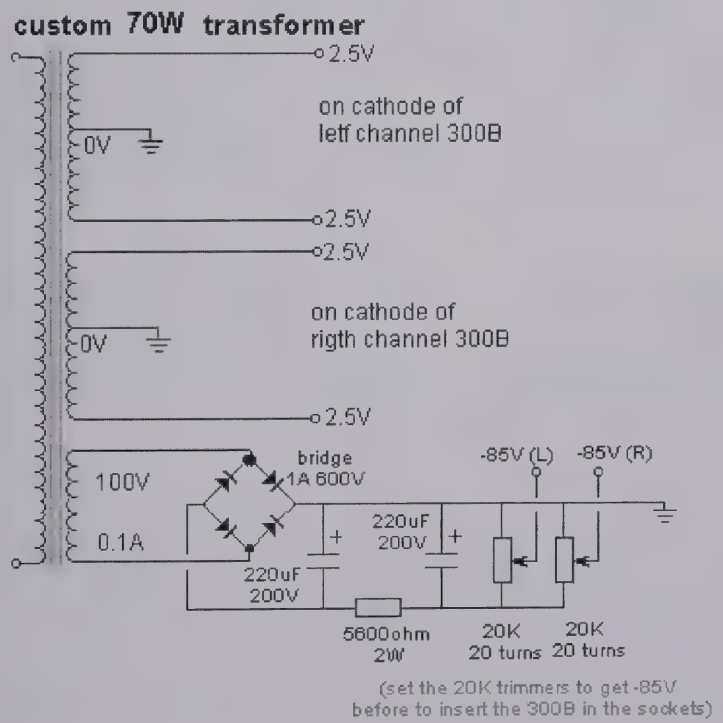
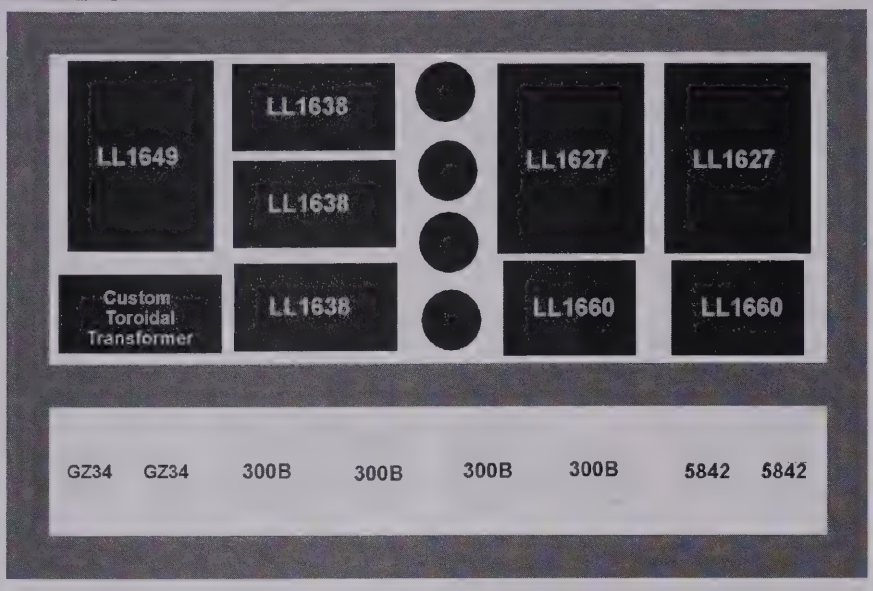


FIGURE 5: Power supply for the 300B PSE with fixed bias.





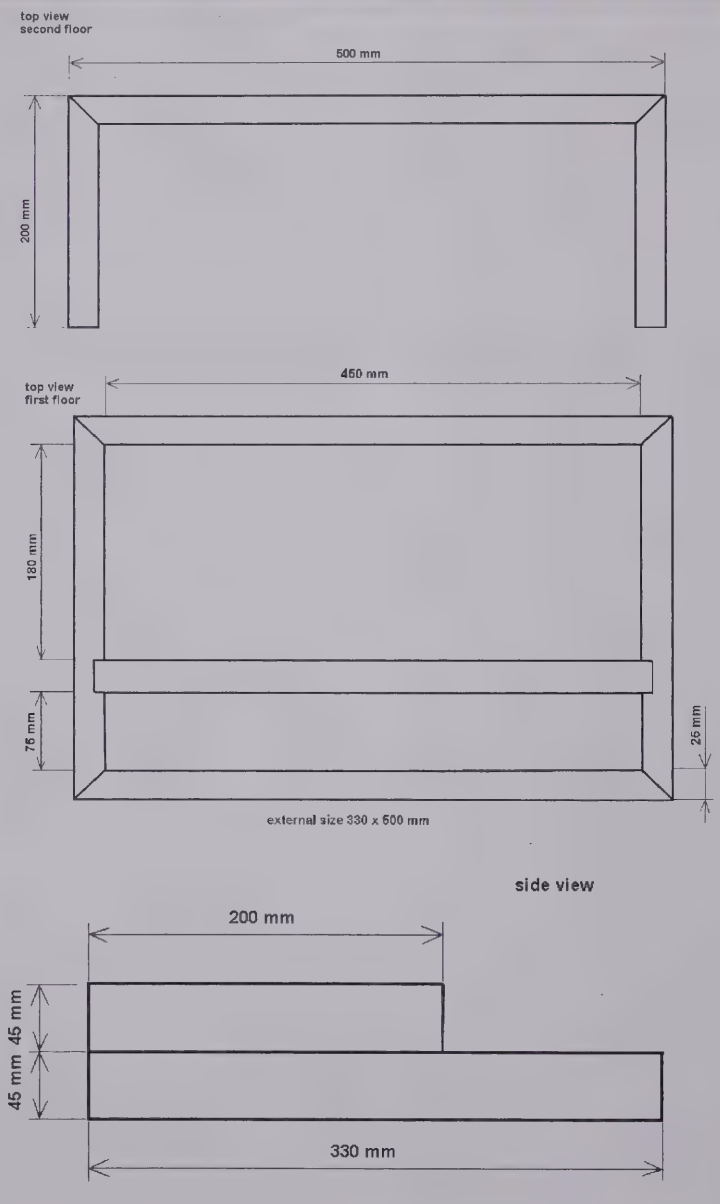


FIGURE 6: Chassis layout and dimensions.

matched for each channel. Better yet, ask for a quarter matched pair. These will, of course, cost more. The connections of the output transformers are very easy to implement if you use the Lundahl PCB_B.

POWER SUPPLY

In the power supply, note my use of the Hybrid Graetz Bridge concept after a Fulvio Chiappetta paper published by the Italian magazine *Costruire HiFi*. He tested and compared this topology versus a pure tube vacuum state power-supply design with a 300B output tube amplifier, and there was no difference while both listening and measuring the output noise spectrum. I built this power supply, and the sonic result is very high quality. Even though it uses semiconductors, the sound depends only on the rectifier tube. The various power supply versions are shown in *Figs. 3-5*.

Since the vacuum tube rectifier is in series with the solid-state diodes, the switching characteristic is that of the lower speed tube device.

OPERATION

This amplifier has sufficient voltage gain to be driven directly by a CD player or DAC so no preamp is required. Adding one could compromise the sound quality. If you need a volume control, you can build an external passive preamplifier using a DACT attenuator and a switch, or mount these and the connectors in the same chassis with the amplifier.

For two years I've used DACT stepped attenuators instead of the usual Alps or Noble pots because their sonic performance is superior. If your CD player has a low output impedance of 500Ω or so, you can use a dual 10k type; otherwise, use a 100k value.

Damping factor is an aspect of amplifier design that is often forgotten in tube amplifiers. The damping factor is in correlation to output impedance. It is very important to keep impedance low because a low damping alters loudspeaker frequency response. I prefer amplifier designs with an output impedance lower than 2Ω. This design's value is about 1.7Ω.

To reduce the R_{out}, choose a higher output transformer turns ratio. This

lowers power output, of course. Here I have used 2300/8Ω to get a turns ratio of about 17. Each 300B sees an anode load of about 4600Ω, which is higher than the usual 300B design of about 3000 or 3500Ω. With this higher anodic load, the 300B also sounds better.

The second aspect that I consider very important is keeping the output tubes in class A1 operation; this means always with negative grid. Many tests confirm that going into class A2, positive grid values inevitably give worse sound. Also, if you configure a driver with high current, the effect of the transition from A1 mode to A2 is always terrible. The only solution for this that I see is cathode-driven output tubes, since this provides a constant load for the driver.

Figure 6 shows the layout design with parts locations and wood size to make the chassis. Please note that some 100µF+100µF 500V ELNA Cerafine capacitors are higher, so you should use a higher chassis (12mm). ✧

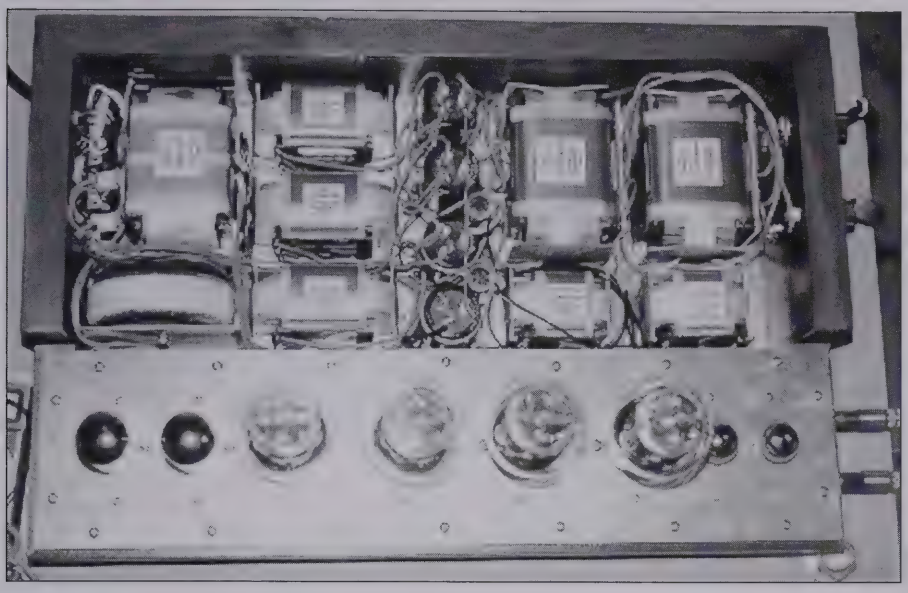


PHOTO 3: Directly overhead the amp.

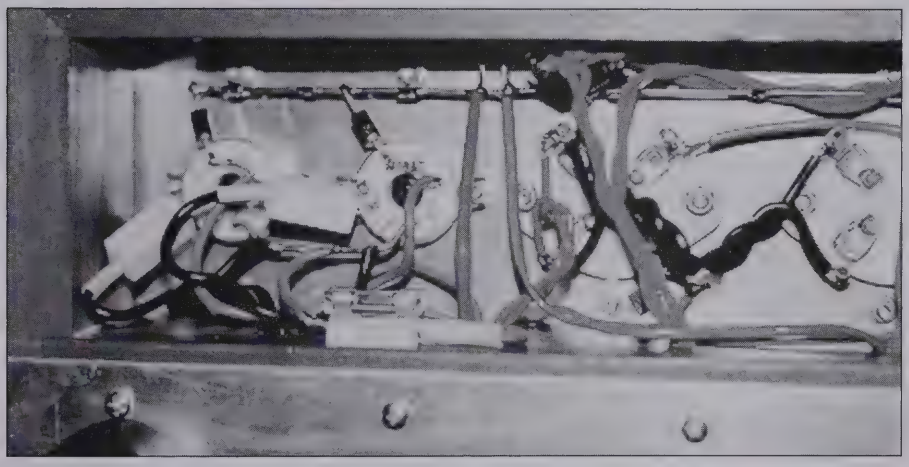


PHOTO 4: Connections underneath the chassis (automatic bias version).

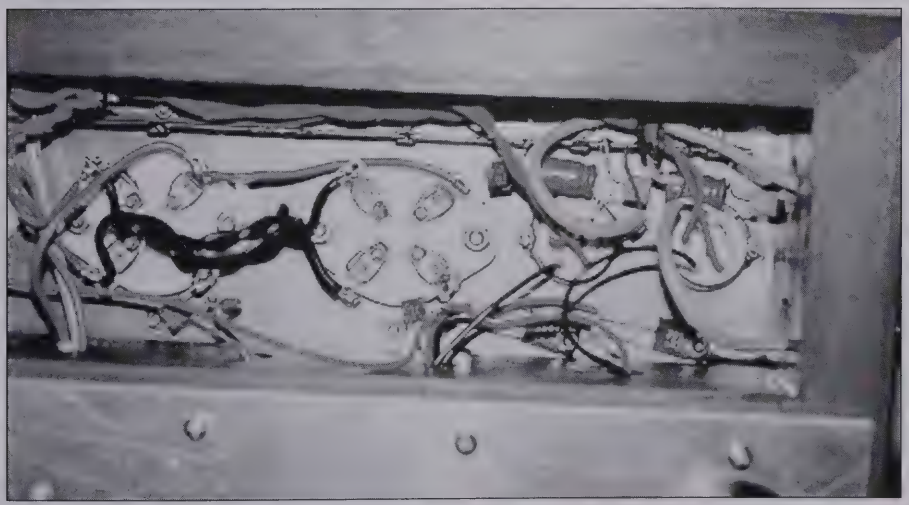


PHOTO 5: Bottom view of input and output section.

You can see the component datasheets on the internet:

- Lundahl transformers
  http://www.lundahl.se/
- Svetlana tubes
  http://www.svetlana.com/
- DACT stepper attenuators
  http://www.dact.com/
- E-Z-Hook wires
  http://www.e-z-hook.com/
- Jensen capacitors
  http://www.jensencapacitors.suite.dk/

Also, contact the following websites for component information:

- Audiokit to get capacitors
  http://www.audiokit.it/
- Welborne Labs
  http://www.welbornelabs.com/
- thetubestore.com
  http://www.thetubestore.com/

[Since this article was written, the 300B is no longer available from Svetlana. Instead, it can be obtained from Westrex (1230 Peachtree Street, #3750, Atlanta, GA 30309, 404-874-4400, Fax 404-874-4415, sales@westernelectric.com, www.westernelectric.com. – Eds]

ACKNOWLEDGMENTS

- Francesco Pinnavaia—an incredible man who doesn't like much music and talks with me every day about audio design
- Massimo De Majo—a jazz composer and musician, owner of a beautiful audio system with the legendary ESL63 electrostatic loudspeakers by Quad and with extensive experience in tests of hi-end products such as Audio Note
- Raul Fazio—a friend who I have enjoyed [illegible]

6C33C-B Loftin White Amp

This Loftin and White amp design features the 6C33C and a 12AX7 complement for a high-quality sound.

By Daniel J.F. David

PHOTO 1: 6C33C-B Loftin and White amp.

The well-known qualities of the 6C33C-B tube—robustness, low-power voltage, easy availability—have encouraged me to continue experimenting with this tube. After having built and listened to a few experimental single-ended amplifiers, I understood the importance, when listening, of having an evenly graduated even/odd harmonic distortion spectrum. This importance was evoked by J. Hiraga in the December 1975 issue of *Revue de Son* (p. 108).

Even more important than the value of the distortion rate is understanding what this harmonic distortion is composed of. However weak, it can directly influence the quality and the tone of the sound. J. Hiraga also expressed the importance of the spectral analysis of the harmonic distortion rate, which is directly related to sound quality and other important criteria. The form of the reproduced square signal is important, and an amplifier that rises too quickly often reproduces exaggerated harmonics in the high ranges.

After a few experimental schematics, I gave up on the SRPP schematic, which produced an evenly graduated distortion spectrum but only odd harmonics. This is a push-pull series; the even harmonics are eliminated. I returned to a simple triode tube in preamplification and rediscovered the qualities of the wonderful "Loftin White" of the 1920s. This is where I found the best results for sound. There is certainly nothing simpler for pleasurable listening.

ABOUT THE AUTHOR

Daniel J. F. David recently retired, after spending his professional career with Xerox Corporation. When he was younger, he received a Superior Technician's Certificate for "vacuum tubes." He now spends free time perfecting amplifier tubes, which should have been his vocation, since he finds so much pleasure in this activity.

INPUT STAGE

The preamplification is a simple 12AX7 with two parallel internal triodes and polarized with a resistor of 470Ω 2W which is bypassed with electrolytic, paper, and tantalum capacitors. The resistor of the plate is 120k, 2W. The grid of the 6C33C-B is directly fed by a voltage of 1k in order to limit the grid current and possible unnecessary oscillations.

One small drawback of the Loftin White schematic is that the Miller effect of the power tube (6C33C-B) reduces high frequencies (*Fig. 1*). The Miller effect is well-known, due to the grid/plate capacity of the tubes multiplied by K+I of the tube in question. Therefore, I parallel the triodes of the 12AX7 in order to reduce, as much as possible, the tube's load and to feed the 6C33C-B with the lowest possible impedance. The attenuation to 20kHz is only 1.5dB.

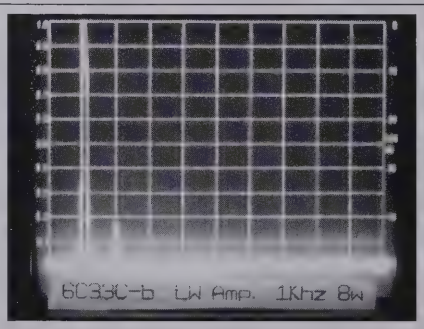


PHOTO 2: Spectrum of 1kHz sine wave—even harmonic only.

This is the one disadvantage of the schematic, but its qualities are otherwise more important. The absence of a coupling capacitor and the low internal voltage of the power tube give the bass tones at the bottom of the spectrum an incomparable quality and produce infinitely detailed and precise medium tones not found in any other type of amplifier.

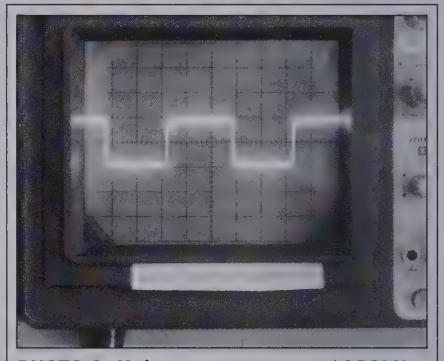


PHOTO 3: Unit measurement at 1000kHz.

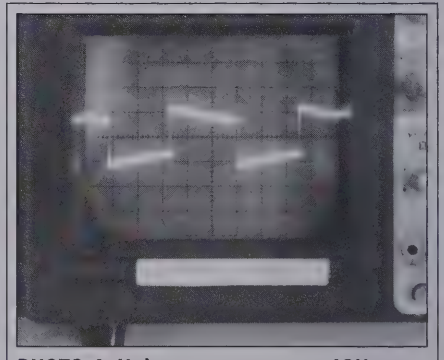


PHOTO 4: Unit measurement at 40Hz.

OUTPUT STAGE AND POWER SUPPLY

The 6C33C-B tube is polarized by a weak DC current of +284V applied between the cathode and the ground. This current is filtered by two electrolytic capacitors of 100µF/450V and a self-induction in a standard pi schematic. The 6C33C-B tube is powered by a voltage of +233V and filtered by a capacitor of 1500µF/350V and a self-induction in a choke input circuit in order to polarize the 6C33C-B before its power voltage is established. The plate of the 6C33C-B tube is 53W. The power transformer is made by Bobinelec.

A galvanometer (optional) in the cathode circuit gives an indication of the cathode current. The potentiometer P2 of 4.7k sets the plate current at 230mA. A safety fuse of 500mA protects the power stage. A continuous DC voltage is applied to the filament of the 6C33C-B tube to avoid too great a difference in the filament-cathode potential. Power of 12W maximum is more than sufficient for the living-room of a modern home.

MEASUREMENTS

A study of the distortion spectrum reveals an even harmonic (*Photo 2*) of 3%, which is not insignificant but without any troublesome effects. The subjective impression of the distortion is weak. However, the even/odd harmonics are very low, evenly graduated and at a practically unmeasurable rate. You can say that this schematic produces essentially an even harmonic. The spectrum is stable in function to the frequency, which is excellent. *Photos 3* and *4* show the unit's measurements at 1000kHz and 40Hz, respectively.

OUTPUT TRANSFORMER

The output transformer, the main piece of the amplifier, uses a parallel C iron-core circuit (X51) of silicon sheets with oriented crystals. The 230mA continuous current component made it necessary to use a powerful iron-core circuit. I calculated the primary self-induction, the number of turns and the air gap.

Mr. Rachez, the manager of Bobinelec, graciously agreed to wind an experimental transformer (*Photo 3*) which permitted the perfection of the definitive BX51s6-1 transformer through laboratory and listening tests. This OPT consists of 1413 primary turns and 135 secondary turns split into five parts (*Fig. 2*). The six secondary turns are parallel in phases. The experimentally corrected air gap is 5/10mm.

POWER SUPPLY

The power supply—besides the filament voltages necessary to the two tubes, one of which has a potential of 150V cc to limit the "cathode filament" voltage of the 6C33C-B tube—also supplies two superposed high voltages. One of these is low and supplies power that polarizes the cathode of the 6C33C-B tube at about 284V through a filter in pi. The other voltage supplies the tube under 233V, 230mA through a choke filter.

The switches, Sw1 and Sw2, are in the off-position at the beginning. Switch

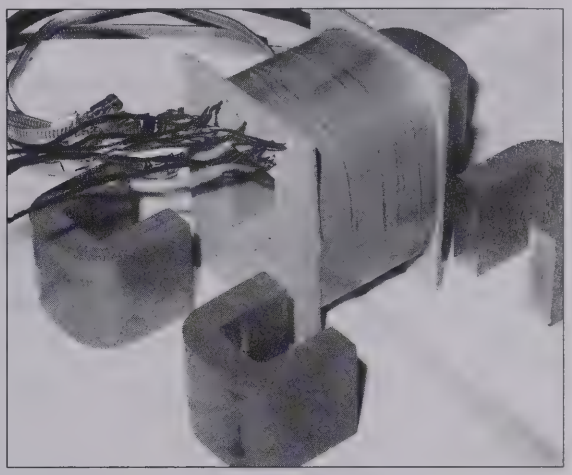


PHOTO 5: Experimental output transformer before assembly.

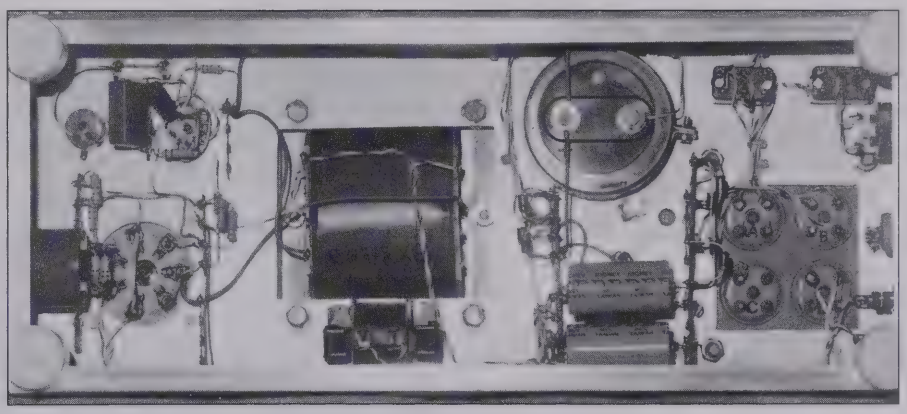


PHOTO 6: Underside of the unit.

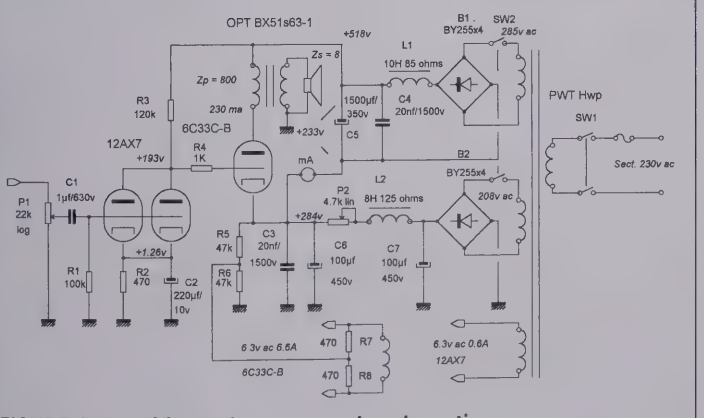


FIGURE 1: Amplifier and power-supply schematic.

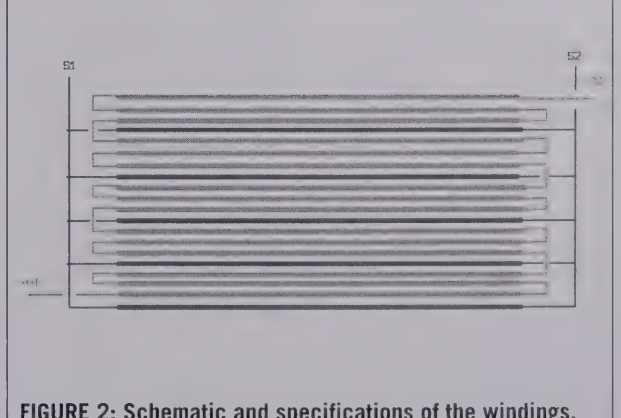


FIGURE 2: Schematic and specifications of the windings.

on Sw1 to supply power to the filaments for about five minutes. Next, switch on Sw2. While the two high voltages increase, the polarization voltage continuously controls the plate current of the tube, which only begins to stabilize after about 20 minutes.

TABLE 1
PARTS LIST

RESISTORS	
R1	100k, 2W metal oxide
R2, R7, R8	470Ω, 2W metal oxide
R3	120k, 2W metal oxide
R4	1k, 2W metal oxide
R5, R6	47k, 2W metal oxide
CAPACITORS	
C1	1µF, 630V metallized polypro
C2	220µF, 10V, mica
C3, C4	20nF, 1500V, mica
C5	1500µF, 350V, electrolytic
C6, C7	100µF, 450V, electrolytic
DIODES	
B1, B2	BY255 × 4 rectifier diode, 1500V 3A
L1	Choke millerioux, 10H, 85Ω, 250mA
L2	Choke millerioux, 8H, 125Ω, 20mA
Power transformer	Pr. 230V, Sec. 285V 0.3A, 208V 0.01A Bobinelec
OPT BX51s63-1	Zp = 800Ω, Zs = 8Ω Bobinelec
P1	potentiometer log. 22k 2W
P2	potentiometer lin. 4.7k 2W

CONSTRUCTION

The amplifier is built on a P-H118 aluminum frame supplied by Antique Electronic Supply. I suggest spray-painting the frame or using a translucent marine varnish. *Photo 4* shows the underside of the unit.

The power transformer and the output transformer were both made by Bobinelec. The company ACEA can also supply these transformers overseas with a more luxurious finish if you wish.

Take the normal precautions for wiring, which should be done solder-lugs-style. Twist the wires powering the filaments using one ground point for the amplification and power stage.

Warning—High Voltage: There is about 520V at certain parts of the amplifier. It is necessary to observe all safety rules.

SOURCES
Bobinelec
67541 Ottwiller - France
(33) 03 88 87 94 27
FAX (33) 03 88 87 92 97
Antique Electronic Supply
6221 S. Maple Ave.
Tempe, AZ 85283
480-820-5411
www.tubesandmore.com

LISTENING TEST

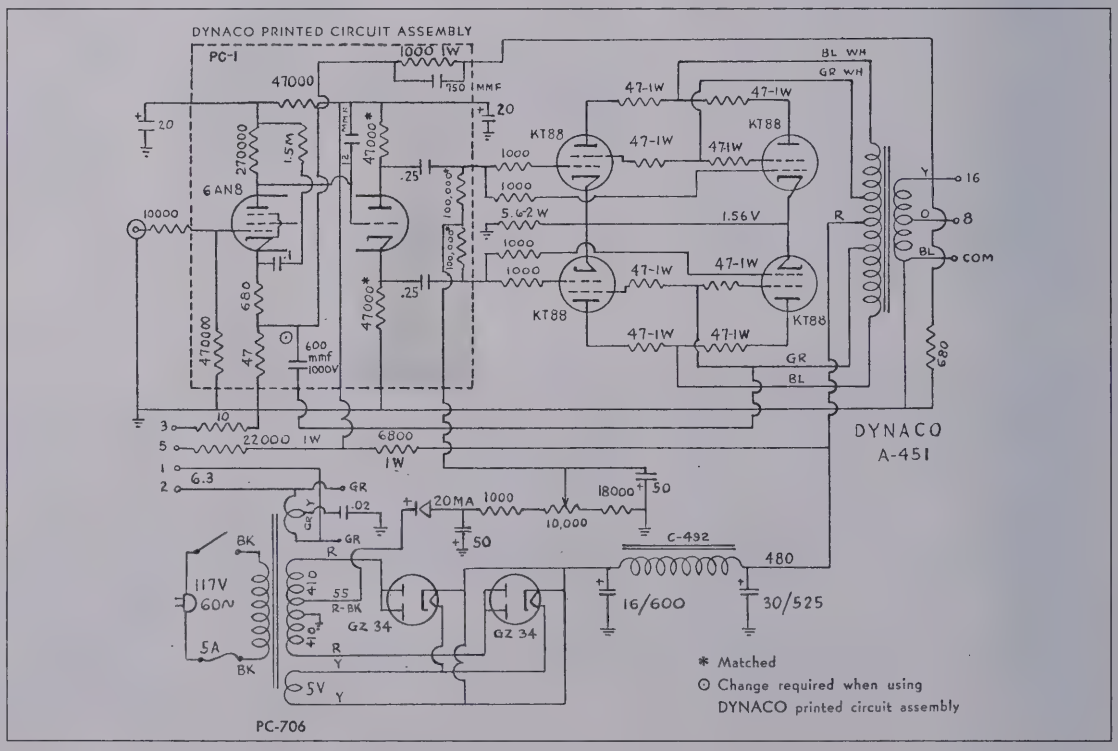
The sound is warm, transparent, and hyper-analytical. The emotion of the recording is conveyed with a rare intensity. The bass tones are natural and very realistic; the medium tones are rich and extremely detailed; the high tones are sufficient and natural.

This amplifier—not necessarily perfect in measure—is of a very high listening quality, which you can enjoy for hours with continuous pleasure. I recommend it to music-lovers attentive to the quality of the notes and tones of the instruments of a symphony orchestra and looking to find the true emotion of a recording. ❖

Translated from French by Gretchen Marie Hromyak.

Classic Circuitry

Economical 50W Amplifier



Courtesy of
G.R. Woodville
(M.-O. Valve Company)

FIGURE 1: Complete circuit diagram of 50W amplifier using KT66 output valves with fixed bias.

A New Stereo Every Night

Talk about flexibility! This use-any-tube amplifier circuit will give you much more mileage out of your tube collection. **By Millard Johnson**

We are all defined by our interests and hobbies (hobby is a label you put on something that allows you to overdo it). Two of my principal interests are building speakers and tube amplifiers. I build several sets of amplifiers every year and build a speaker whenever I can find a place for one. I have projects going on all the time.

SYSTEM EQUIPMENT

When building speakers and amplifiers, it is an easy step to have biamplification or triamplification systems. My current main speaker system uses Morel MDT 33 tweeters, Morel MSD 56 2⅛″ domes for the midrange, and six 6″ lower midrange speakers connected to their own amplifier. I am working on an article featuring this speaker system for an upcoming issue of *audioXpress*.

The subwoofer uses two 10″ Eclipse speakers mounted isobarically in a vented 2ft^3 enclosure. I tried all the locations in my listening room and found that the best response was behind the speakers, near the corner. The woofers, when placed in their optimum spot, seem to energize the room. My computer says this woofer should have an f_3 of 24.7; in the best spot it has an f_3 of +6dB at 24Hz.

Until recently all the amplifiers I had build were push-pull, so I needed some convincing that single-ended amps had merit. About a year ago, I built my first SE amp. I used 211s and an article from *Glass Audio*, and the sound is wonderful! This experience with the 211s led directly to the amplifier in this article.

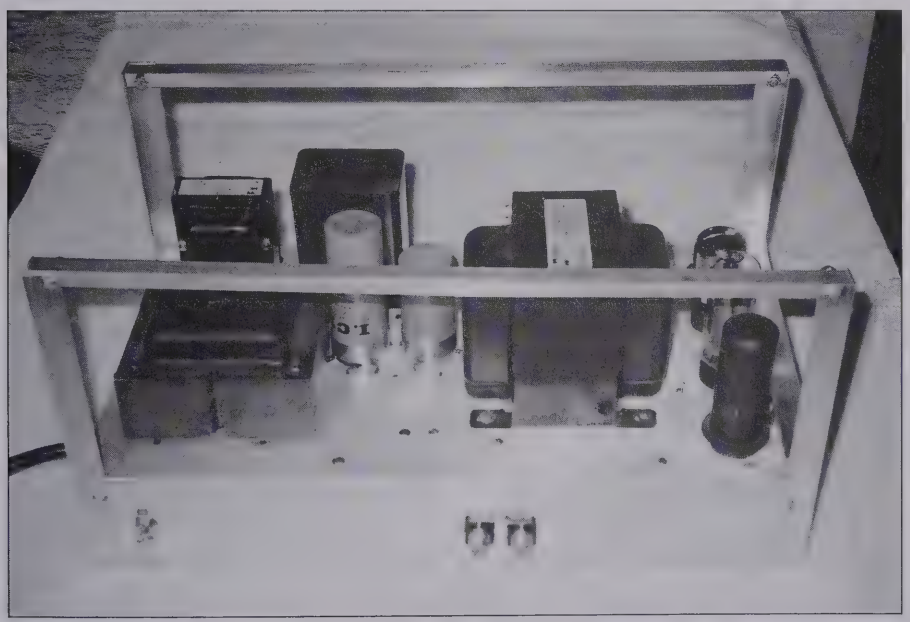


PHOTO 1: Front view of completed amp.

TABLE 1
TUBES CLASS A, 250V

TUBE	BIAS	WATTS	IMPEDANCE	QUANTITY
6L6 (any)	72mA	2—6.5=13	2500/=1250	2
6V6	45mA	4—4.5=18	5000/=1250	4
EL34	70mA	2—8=16	3000/=1500	2
6550/KT88/KT990	140mA	12.5	1500	1

AN AMP FOR ALL TUBES

My use-any-tube amplifier that this article describes has a very special sound quality (*Photos 1* and *2*). In comparison with any others I have ever heard, including the 211s, it seems to better define and layer the sound stage. Leading transients, such as a piano key when struck, sound incredibly natural. It is difficult to describe the amp because it adds so little to the sound, but if you like to experiment with and listen to tubes, this is a tube rollers paradise!

I have tried many tube combinations. My recipe for the day is one RCA metal 6L6, one G.E. 5881, and one Svetlana EL34 in each amplifier. This ability to change tubes (*Table 1*) and experience the sound is like taking home a new stereo every night!

Parallel single-ended amplifiers are really different from push-pull, where you prefer to have tubes that match! In parallel single-ended, you can do outrageous things such as having a 6L6 and a KT34 run together, or two 6L6s and one KT34 or a single 6550 running by itself. The combinations are endless.

I have been collecting tubes as long as I have been collecting circuits. My collection includes about 50 6L6s. I had tried a couple of times to put together a killer 6L6 amp and always switched to EL34s, 6L6GCs, or 6550s because you can run them at a higher plate voltage

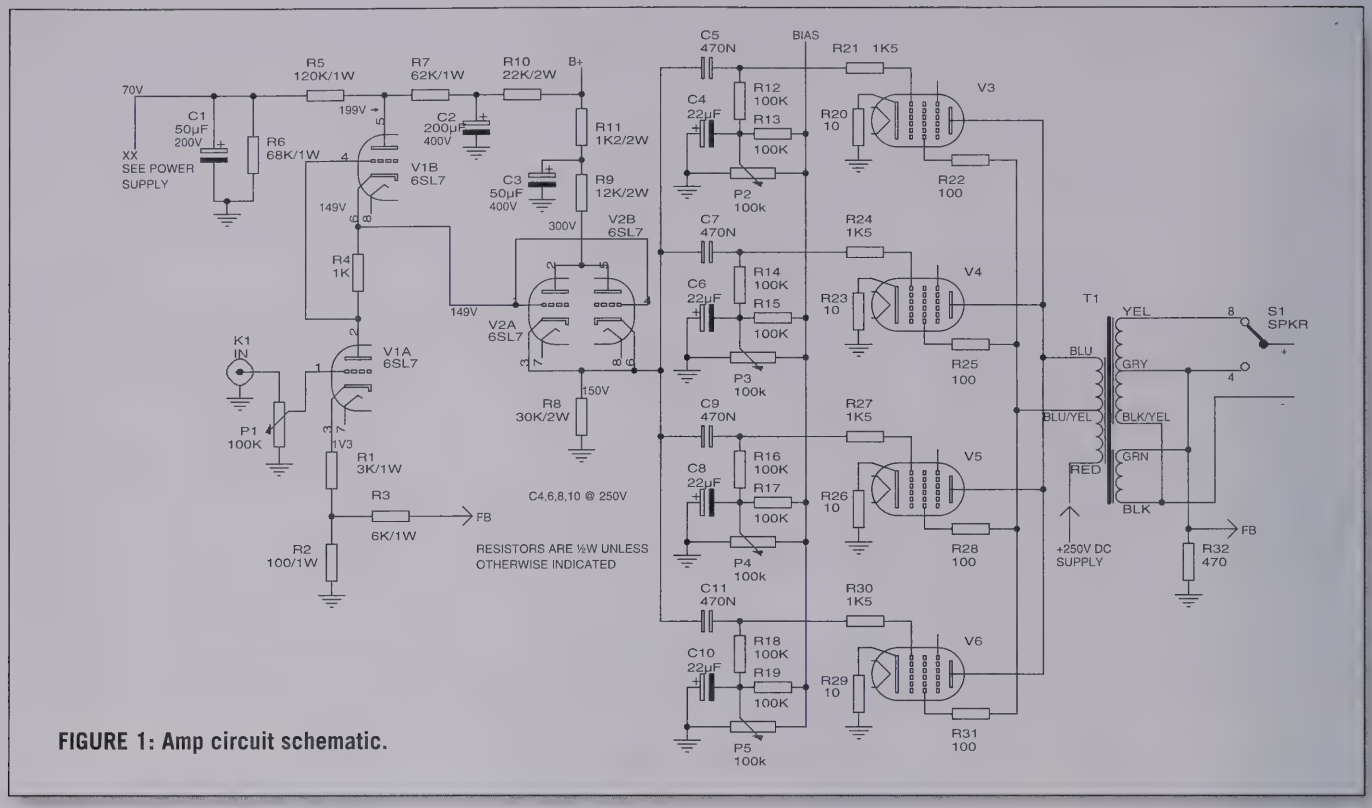


FIGURE 1: Amp circuit schematic.

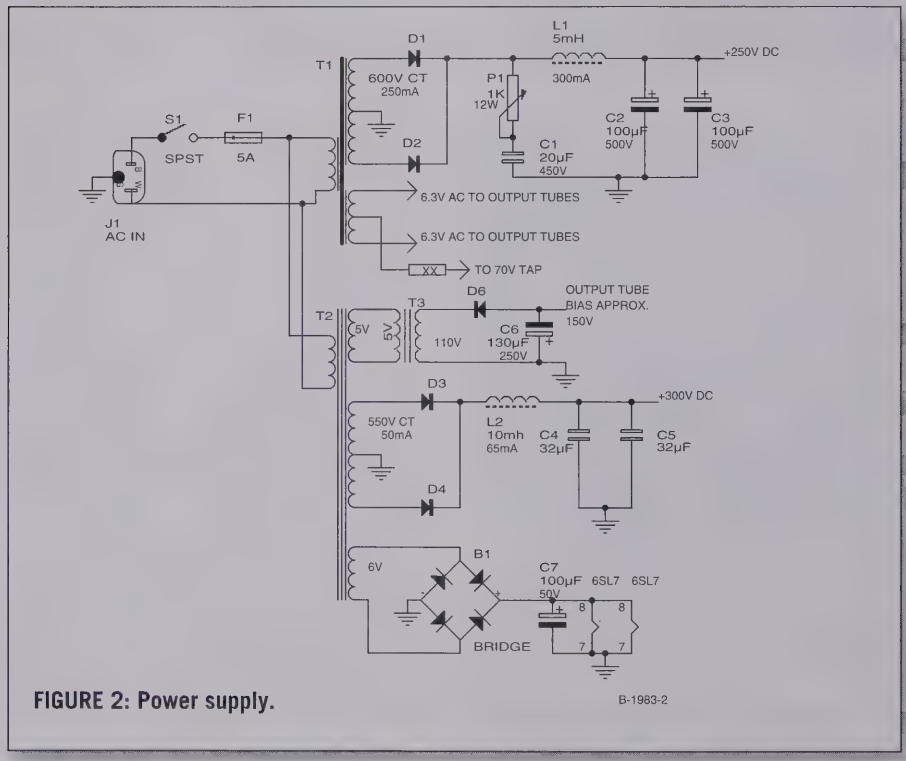


FIGURE 2: Power supply.

(6L6s at 360V, compared with EL34s or 6L6GCs at 450+).

My tube manual shows that 6L6s run Class A at 250V, but EL34s, KT88s, KT90s, 5881s, 6V6s, KT 66s, and 6550s also run 250V Class A. Not only that, but they all have nearly the same internal wiring. The only distinction is that 6L6 tubes have the suppressor grid going to pin 8, and EL34s have it going to pin 1. This suppressor grid is actually composed of beam-forming plates connected to the cathode to keep stray electrons from going back to the screen grid.

You need to remember always to solder a wire from pin 1 to 8; this solves the problem, and you can use any of the tubes I have mentioned. All the tube amplifiers I build have a 10Ω resistor going from the 1 8 tube pins to ground, which makes it easy to measure the current with your voltmeter; e.g., 400mA = .4V on your meter.

IMPEDANCE MATCHING

It is necessary to make the impedance of the tubes match the impedance of the transformer. The output of the tubes is cumulative. This means that if a tube puts out 6W, four of them would put out 24W. It is not necessary to match 1200Ω of the output transformers exactly, but you shouldn t depart too far from this number.

The value of the tube impedance is figured like that of a resistor. Two tubes in parallel are like two resistors in parallel. Two 3000Ω-impedance tubes produce 1500Ω impedance when connected in parallel. If you like simple circuits, you will love this one. It has only one coupling capacitor to each socket!

The amp uses two completely separate high-voltage power supplies, one for the output tube supply, and one for

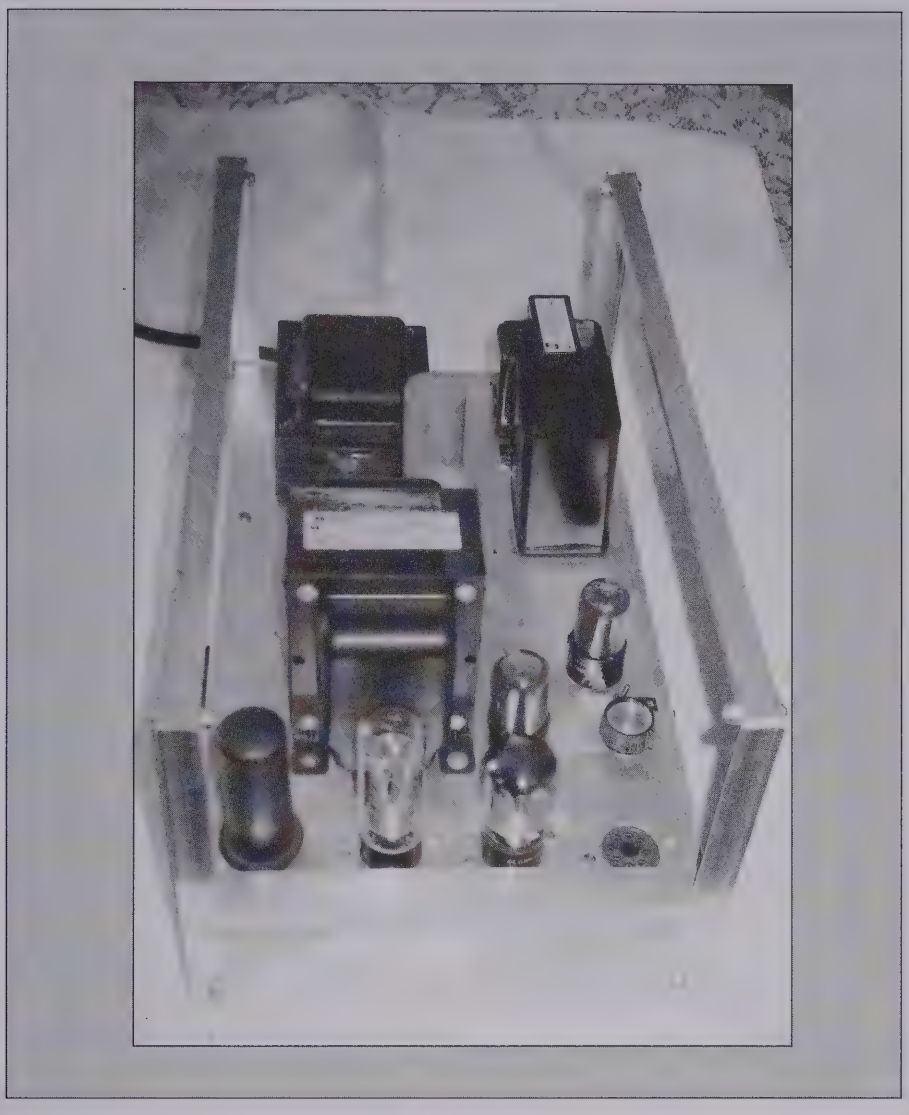


PHOTO 2: Side view.

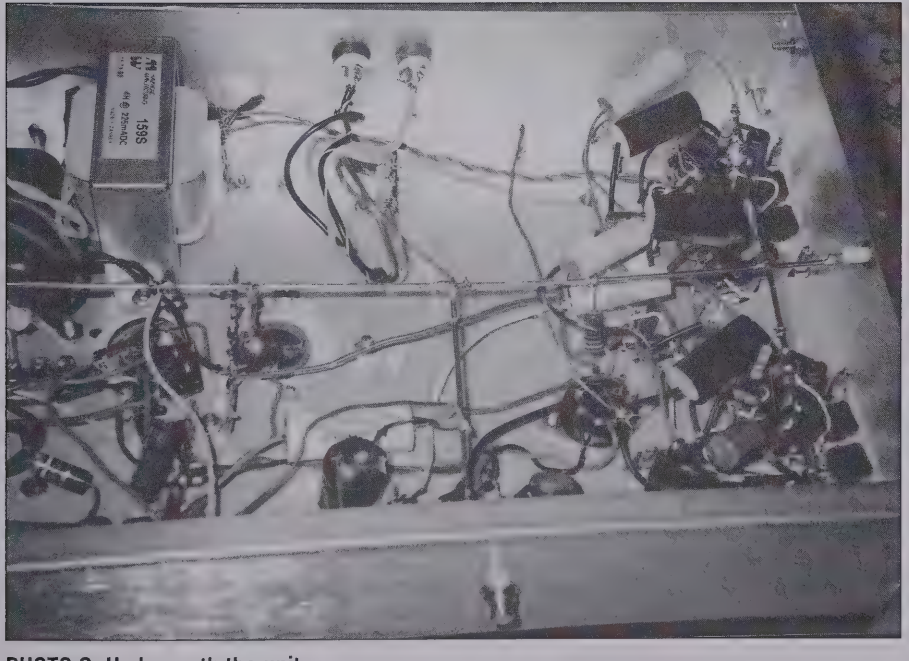


PHOTO 3: Underneath the unit.

the two 6SL7s. I recommend the adjustable-voltage feature shown in *Fig. 1*. This filter operates somewhere between choke and capacitor input conditions.

In the circuit schematic (*Fig. 2*), you will see a variable resistor in series with the positive lead of the input-filter section. This resistance, when fully in the circuit, seriously limits the ability of the capacitor to charge; as a result, the output voltage is reduced nearly to the value of a choke input. On the other hand, when the resistor is reduced in value, the input charges to a more normal voltage, and the output reflects this change.

BUILDING TIPS

Before you do any drilling or hole punching, place the transformers, tubes, and other major parts on the chassis and move them around to achieve the best-looking and most logical arrangement. Then drill and punch. Wire the power transformer first, including filaments and bias supply, on/off switch, and fuse (*Photo 3*). Then, without the high-voltage diodes connected, plug in the amplifier and check the filaments and bias supply. If you send high voltage and power to the filaments before checking bias, your tubes will self-destruct!

Next, wire the four front tube sockets and test them for bias adjustment. Finally, finish the wiring. The last thing to solder will be the four coupling capacitors.

Several years ago I did a listening test with all the popular coupling capacitors. I spent several hundred dollars to find out that a Hovland MusiCap in the signal path is money well spent. My preamplifier is an Audio Research LS-3. The main reason I opted for a solid-state preamp is that I like to leave it on all the time. I used Hovland caps in the signal path and bypass, and it made a surprising difference.

This amplifier is so special and sounds so good that I am glad to share it with you. I hope this use-any-tube amplifier will inspire you tube builders to dig out your chassis punches and warm up your soldering irons. Please let me know about your experience with this amplifier at mjohn0690@aol.com. ❖

THD Cancellation Capabilities of Cascade Stages

Discover how cascade stages reduce THD when you use these harmonic cancellation techniques. **By Stefano Perugini**

A common-cathode triode stage exhibits an harmonic spectrum decreasing (in a monotonic way) with the frequency, with the greatest contribution furnished by even harmonics (particularly the second). A similar pentode stage presents a wider spectrum and therefore a general increase in total harmonic distortion (THD) values and a greater contribution from odd harmonics.

These two different behaviors between triodes and pentodes in the common-cathode configuration can be easily justified by observing that the mutual dynamic characteristic (the true entity that characterizes in an unambiguous manner the nonlinear behavior of any amplifier stage) is easily referable to the second and third order geometric curve for triodes and pentodes, respectively (*Fig. 1*).[1]

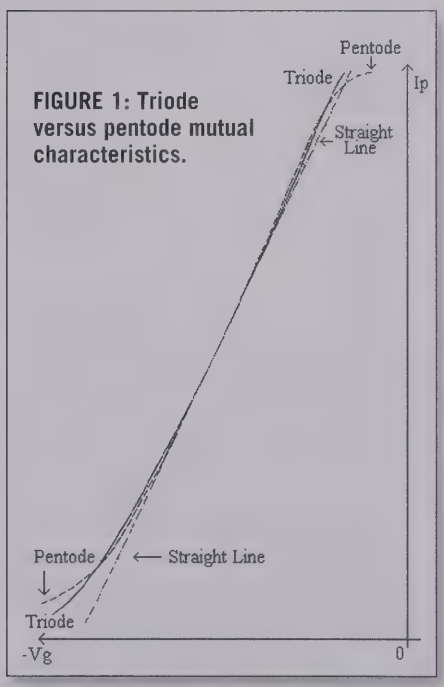


FIGURE 1: Triode versus pentode mutual characteristics.

This different behavior of the two classes of thermionic devices surely favors triodes, since even harmonics are simpler to reduce. In fact, when correctly implemented, triode stages with implementation of harmonic cancellation techniques (HCT) can easily exhibit very low values of THD if phase distortions are negligible.

ANALYSIS AND EXAMPLES

In the AC domain, a triode cascade stage is reproduced in *Fig. 2*. This schematic represents most of the circuits that you will meet, e.g., *Figs. 3–6*. Clearly, other variants exist with pentodes and/or buffers that can be represented with the schematic of *Fig. 2*. These circuits, in their disarming simplicity, fit well with the HCT; furthermore, they are easy to build, and above all they sound good.

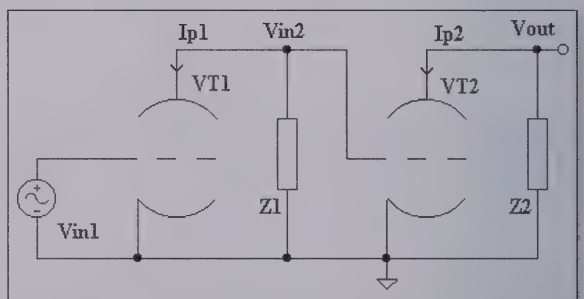


FIGURE 2: Cascade stage in signals domain.

The variations of this design, in which inductor or transformer coupling between the stages is achieved (*Figs. 5* and *6*), are more immediate and easy to manipulate, since changing the resistor in the grid's output tube is often sufficient to put the HCT in the best operational condition without dangerously altering the bias of the drive stage. On the power-amplification side, I believe the only constraint is the proper choice of the tube for the drive stage.

The main characteristics are a "good" mu and a low r_p (that is a high g_m), as well as a reasonable power dissipation. The usual receiving tubes used in traditional amplifier design, such as ECC83/12AX7, 6SN7, and so on, can yield unsatisfactory results; therefore I

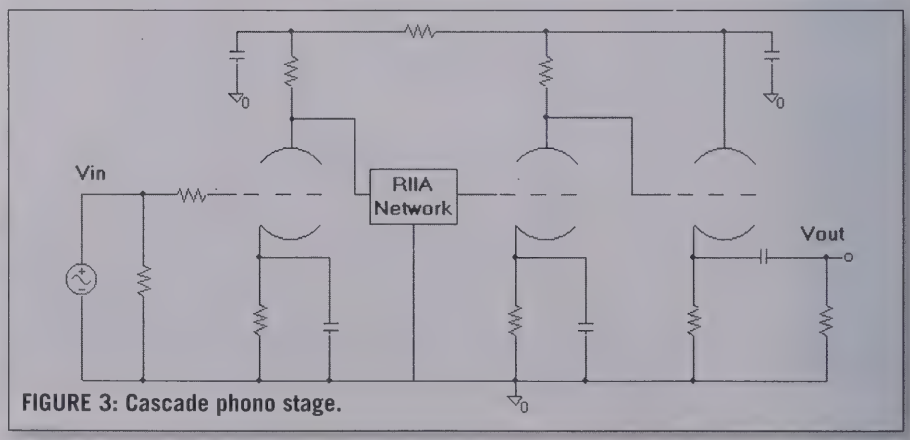


FIGURE 3: Cascade phono stage.

ABOUT THE AUTHOR

Stefano Perugini earned a degree in electronic engineering in 1992 from the University of L'Aquila (Italy). After employment as reactor and system-control engineer, he now works as a project manager in the field of high-energy physics and medical instruments based on photomultiplier tubes. He is also active as a consultant for professional audio companies.

prefer vacuum tubes with the best electrical performances, e.g., WE437A, 3A167M, EC8020, E55L, E810F, and others. Unfortunately "high perveance" tubes are rarer and expensive. Of course, you can resort to composite configurations like SRPP, mu-followers, and cascode and cathode followers in order to surpass the inherent limitations of standard tubes.

I stress the importance of good drivers, which are essential if you decide to design a Class A2 amplifier or if you aim to explore the enormous potentials of big direct-heating transmitting tubes such as 211s and 845s that usually can present grid current already for weak negative grid voltages. Furthermore, in these tubes the input capacitances are not negligible and they require a wide driving signal.

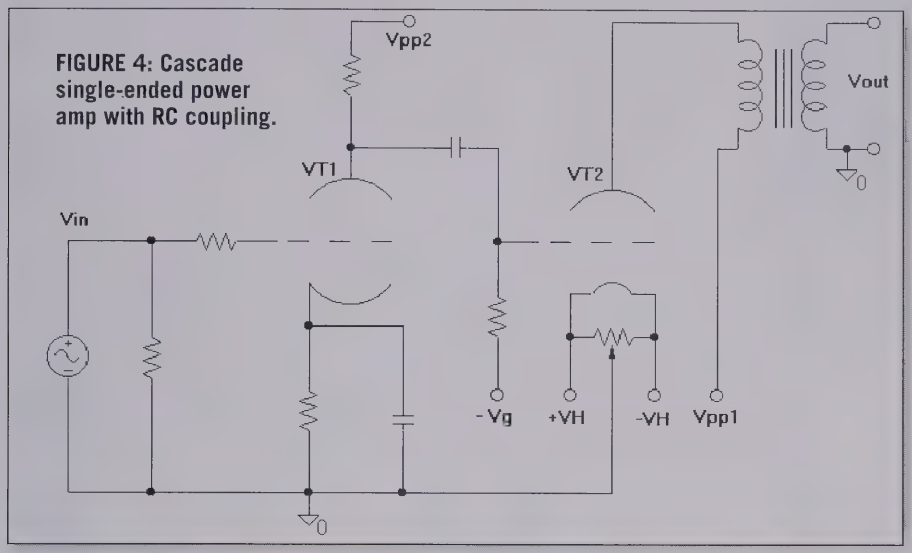


FIGURE 4: Cascade single-ended power amp with RC coupling.

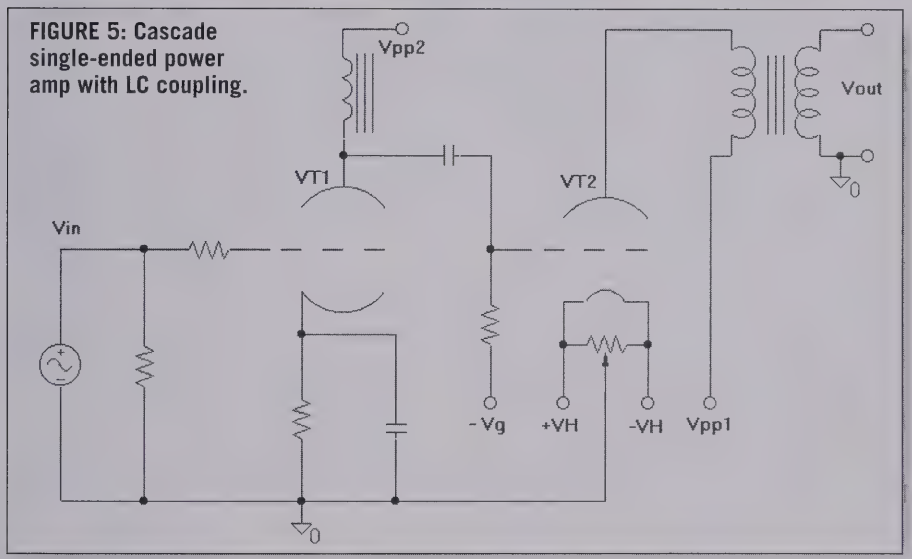


FIGURE 5: Cascade single-ended power amp with LC coupling.

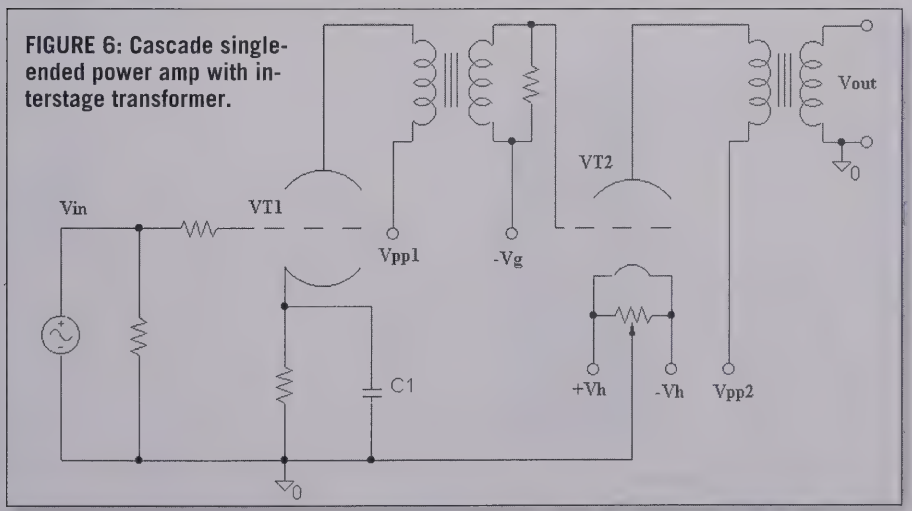


FIGURE 6: Cascade single-ended power amp with interstage transformer.

EXTRACTING COEFFICIENTS

From *Fig. 2* you have:

$$Ip_1 = g_{11}\,Vin_1 + g_{12}\,Vin_1^2 \quad [1]$$
$$Ip_2 = g_{21}\,Vin_2 + g_{22}\,Vin_2^2 \quad [2]$$

where g_{ij} coefficients are constants inherent to the mutual dynamic characteristics of the two gain stages, assuming effects higher than second-order are negligible. You can extract these coefficients with a mathematical or experimental method. In the mathematical approach, you can proceed analytically or numerically. I prefer the latter because you can use the computer to crunch the numbers. Since from *Fig. 2*,

$$Vin_2 = -Z_1\,Ip_1 \quad [3]$$
$$Vout = -Z_2\,Ip_2 \quad [4]$$

by sustituting equations [1] and [2] in [3] and [4], respectively, it's easy to reach the following expression for the output voltage:

$$Vout = g_{11}g_{21}Z_1Z_2Vin_1 + (g_{12}g_{21}Z_1Z_2g_{11}^2g_{21}Z_1^2)\,Vin_1^2 + 2g_{11}g_{12}g_{22}Z_1^2Z_2Vin^3 \quad [5]$$

where:

$$Vin1 = Vp\,\sin\omega t, \quad [6]$$

and therefore:

$$Vin1^2 = \tfrac{1}{2}Vp^2(1 - \cos 2\omega t) \quad [7]$$
$$Vin1^3 = \tfrac{1}{4}Vp^3(3\sin\omega t - \sin 3\omega t). \quad [8]$$

Equation [6] is the mathematical expression of the input signal, while [7] and [8] are derived with a bit of trigonometry. Two main considerations emerge from equation [5]:

- In the hypothesis of a second-order mutual dynamic characteristic for the common-cathode stages, the output signal presents also a third-order component;

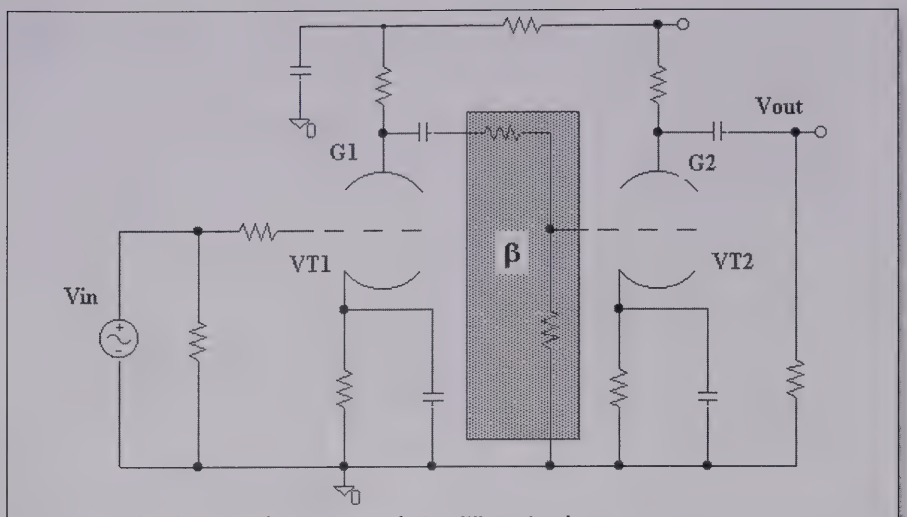


FIGURE 7: Circuit for the improvement index (II) evaluation.

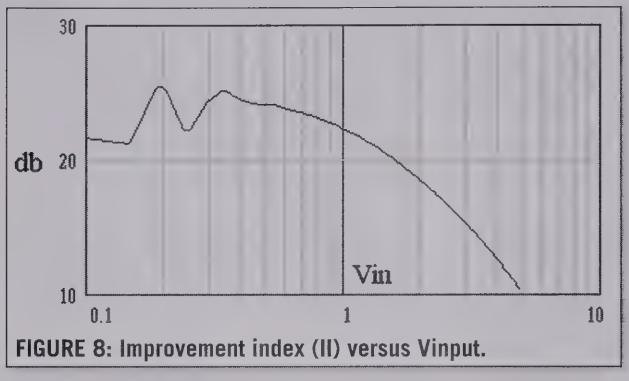


FIGURE 8: Improvement index (II) versus Vinput.

- The algebraic expression within the parentheses in [5] underlines the theoretical possibility for an annulment of the second-order component, thanks to [7] and [8].

Unfortunately, the exact values for Z_1 and Z_2 that permit a reduction or nulling of the second-order effect are hard to find, since:

$$(g_{11},g_{12}) = f(Z_1) \quad [9]$$
$$(g_{21},g_{22}) = f(Z_2), \quad [10]$$

and the connection between the coefficients and impedance is not immediate. Fortunately you can easily resolve this problem from a practical point of view and with a good approximation by resorting to both circuit simulation and practical measurements.

HCT EFFECTIVENESS

Generally, by applying HCT, a reduction of the second-order component in the case of triodes is followed by a THD reduction and a small growth of the third-order component. The latter effect involves also an aesthetic result, since, in this manner, you obtain symmetry in the shape of the reproduced signal, with respect to the amplitude scale.

At least theoretically, you can obtain the maximum effectiveness for the HCT when VT1 and VT2 in *Fig. 2* are identical, with the same bias point, and when Vin1 and Vin2 are equal. Actually the last condition requires an explanation, because here it s practically impossible to make the two signals truly equal. In fact, although Vin2 can be brought back to an amplitude similar to that of Vin1 (more details subsequently), it will always be a signal with an harmonic content richer than the input signal, since it will contain a trace of the distortion caused by VT1.

You could use the circuit in *Fig. 7* to experimentally appraise the significance of the previous considerations. The concept is simple: the input signal, Vin1, is amplified by G_1 (the first-stage gain), and is out-of-phase. You can represent this signal in the following manner:

$$-G_1 \text{ Vin} + \delta_1 \quad [11]$$

where δ_1, the error produced by the first triode, includes distortions, noise, hum, drift, and so on; next, the criterion network β (that could also contain a reactive element for frequency compensation) attenuates the amplified signal by the value:

$$\beta = 1/G_1, \quad [12]$$

and finally, after the second stage amplification:

$$\text{Vout} = -G_2 [(-G_1 \text{Vin} + \delta_1)\beta] + \delta_2, \quad [13]$$

where, likewise, the first-stage s G_2 and δ_2 are the gain and error, respectively, for the second one. By assuming

$$G_1 = G_2 = G = 1/\beta, \quad [14]$$

equation [13] is reduced to the following:

$$\text{Vout} = G \text{ Vin} \quad \delta_1 + \delta_2; \quad [15]$$

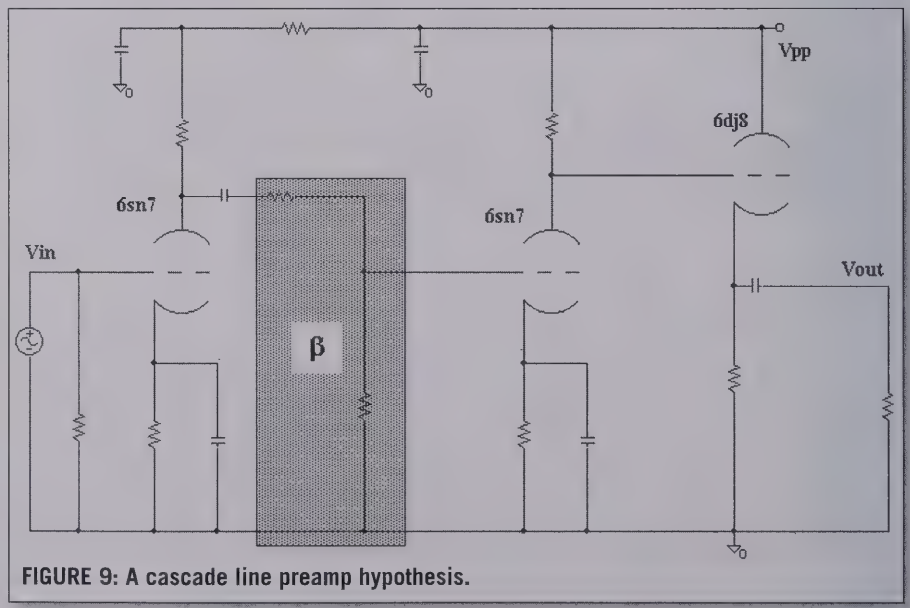


FIGURE 9: A cascade line preamp hypothesis.

and δ_1 and δ_2 are similar if both triodes are similar in their dynamic behavior, and the input signal swing is small; therefore, a lower value in the output signal THD can result.

THE IMPROVEMENT INDEX (II)

The reduction mechanism of even harmonics clearly hasn't the same effectiveness you can find in ideal push-pull structures, where the input signals are really equal, although out-of-phase. In cascade stages as in *Fig. 7*, the second stage receives an out-of-phase signal with the "harmonic imprint" caused by the first one. You can define an improvement index (II):

$$II = 20\,Log_{10}\left(\frac{\text{THD 1st Stage}}{\text{THD in Output}}\right), \qquad [16]$$

and its graphic (*Fig. 8*) shows good performance of the cascade for small input signals, where the harmonic content in the first-stage output is not elevated. For both tubes and bias points, see the *Receiving Tube Manual*.[2]

The mechanism that characterizes the behavior of the circuit in *Fig. 7* could be used, appropriately adapted, to realize an electronic phase inverter for push-pull amplifiers and for a line stage with low THD (*Fig. 9*). A similar preamplifier presents a cumulative gain as the first stage, a low THD, and, thanks to the cathode-follower, a low output impedance.

Clearly, other circumstances could require different bias points or vacuum tubes for the basic structure in *Figs. 7* and *9*. For this situation, an "ad hoc" examination permits the best application of the HCT, although the procedural mechanism is the same. ❖

REFERENCES

1. F. Langford-Smith, *Radiotron Designer's Handbook*, RCA, p. 509, 580–81, Chap XIV, 1953.
2. RCA, *Receiving Tube Manual*, Technical Series RC-19, p. 341, 1985.

Glass Shard

Single-Ended Push-Pull Output

I have read Norman Crowhurst's excellent description of configurations and characteristics of various power amplifier output stages (Jan. and Feb. '01 *audioXpress*). He points out that output transformers for most of these configurations are special and are not generally available. The configurations discussed are push-pull, which, as a practical matter, are necessary if you desire more than low power at low distortion. And, of course, an output transformer is necessary in vacuum tube designs.

The output stage of most higher power amplifiers is class AB or class B, in which plate current flows less than a full cycle, characteristically, in each half of the output transformer primary. This may give rise to a transient[1] at the current interruptions because the windings are not perfectly coupled, therefore causing distortion. The transient can be eliminated by bifilar winding the primary halves—which is usually not practical—or by extensive interleaving.

Another configuration exists called "single-ended push-pull," which is neither plagued by the switching transient problem nor does it require a special transformer. However, the transformer must have a split primary and be capable of withstanding the plate supply voltage between the primary halves. Many high-quality stock transformers, for example, the UTC Linear Standard line and others popular a few years ago, meet these requirements. A number of them may still be around but not in use.

Figure 1 shows a single-ended push-pull output stage that I have used. I got the idea from the Proceedings of the I.R.E.[2] Note the tubes are in audio series but in parallel on the plate supply. The output transformer primary halves are in AC parallel by virtue of a capacitor (about 40μF) tying the halves together. The phase inverter plate resistor is returned to the plus (+) side of the transformer half and swings at the full output voltage. Since both the plate and cathode resistors of the phase inverter are of equal value, both output tubes receive equal drive in opposite phase.

Audio amateurs wishing to try something a little different might be interested in this one. ❖

J. L. Markwalter
Port Charlotte, Fla.

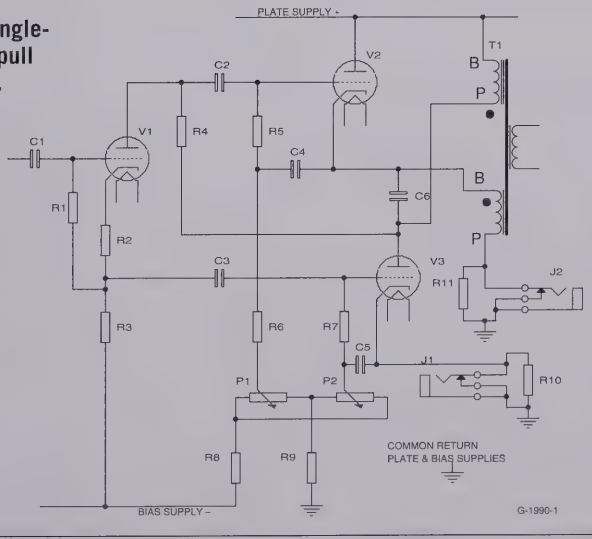


FIGURE 1: Single-ended push-pull output stage.

REFERENCES

1. A. Pan-Tung Sun, "Some Transients in Class B Audio-Frequency Push-Pull Amplifiers," Proc. I.R.E., Vol. 24, p. 1522, November, 1936.
2. Proc. I.R.E., Jan. 1952, p. 8 (title and author recorded in my notes).

A 70W Integrated Amp

The latest effort from this popular tube-amp designer delivers convenient power to meet all your hi-fi needs. **By Joseph Norwood Still**

This integrated amplifier features push-pull KT88s (tetrodes) with an output of 70W in the ultralinear mode. The amplifier uses only a driver and inverter (two-stages) to drive the KT-88s and ensure maximum stability over the audio frequency spectrum. The sensitivity of 1.5V RMS for a 70W output or 0.8V RMS for a 10W output with 8dB feedback applied (or in 0dB feedback mode, 0.8V RMS for 70W output) permits operation of CD, tuner, tape, satellite audio, and even a remote phono preamplifier. The feedback is limited to a modest 8dB maximum and can be varied with a front-panel control for a minimum of 0dB feedback. It is very stable and provides low distortion throughout the audio spectrum to its full output and provides a realistic, lively sonic presentation.

This stereo amplifier is a completely self-contained system (*Photo 1*). The front-panel controls of the amplifier feature an input selector switch, negative feedback control, and an on/off power switch. The four positions of the selector switch are used for line-level operation, while the fifth position is used for phono use. Separate stereo (R/L) volume controls prevent crossover distortion.

The Hammond transformers and 8SN7s (NOS) are available from Antique Electronic Supply, and the Sovtek KT-88 tubes are available from Parts Express. The chassis and most other parts are available from Antique Electronics Supply, Radio Shack, and All Electronics. The amplifier will satisfy the hi-fi requirements of all but the ultra-purist. You can build it with a reasonable amount of work for about $500.

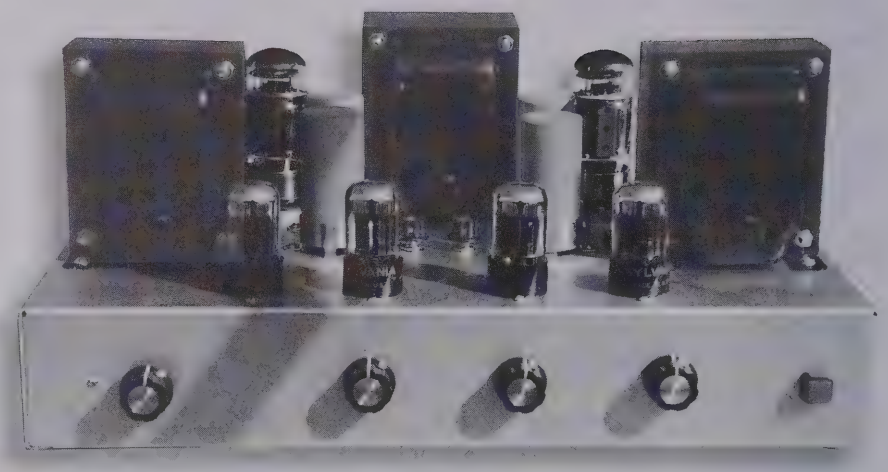


PHOTO 1: The 70W ultralinear amplifier.

70W ULTRALINEAR AMPLIFIER

The circuit diagram of the amplifier is shown in *Fig. 1*, and the parts list in *Table 1*. The design features KT-88s connected in ultralinear configuration preceded by an 8SN7 long-tailed phase inverter and an 8SN7 cascode first stage. The ultralinear operation shares some of the best features of the triode, which is primarily improved frequency response, improved damping, and reduced distortion. It has greater efficiency than a triode, provides five times the damping of a tetrode, and has self-generated feedback.

A review of the tube data in *Table 2* reveals that the dissipation level of 34W is within the recommended dissipation ratings for these tubes. I obtained the 70W operation with a bias of –65V DC, thus providing a 45V RMS drive signal to the control grids of the KT-88s. No clipping occurred at the 70W level.

Important: The KT-88s are operated in the fixed bias, class AB1, ultralinear mode to provide the "coolest" operation of these tubes and therefore extend their operating life. In this mode, the KT-88s operate at a typical 34W of plate dissipation with a "resting," zero drive signal. The typical plate dissipation with maximum signal drive is 35W. This is well below the maximum dissipation rating of 59W (plate and screen) specified in the tube data sheets.

It is important to note that for 540V DC operation of the KT-88s, in the ultralinear (self-bias) or triode (self-bias or fixed-bias) mode, these tubes are

ABOUT THE AUTHOR

Joseph Norwood Still [illegible]

operating near their maximum dissipation levels when adjusted for a reasonable distortion output. In my opinion, you should not operate these tubes in any of these modes at the higher plate voltage ranges, because a diminished life cycle would result. However, you can operate these tubes at 540V DC in the tetrode (self or fixed-bias) mode, where typical "resting" and maximum signal plate dissipation ratings of 30W are well within the KT-88 plate dissipation limits. Note that the tetrode dissipation levels are very similar to the plate dissipation levels of the fixed bias, class AB1, ultralinear mode.

DRIVER STAGES

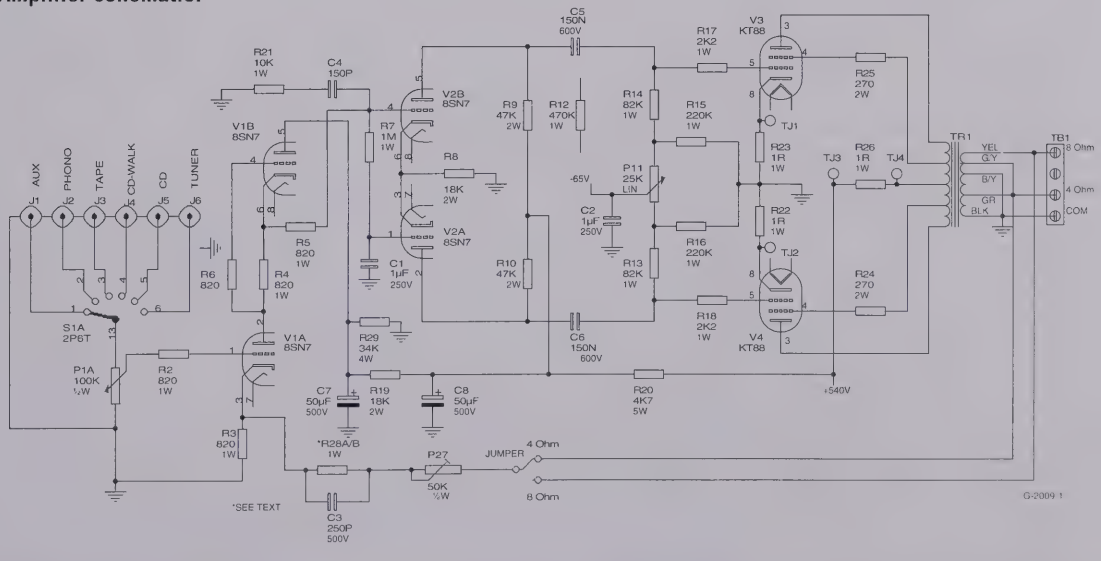
The cascode-connected 8SN7 is used for the first stage of the amplifier (*Fig. 1*). (The cascode provides more gain than a single triode and better stability than a cascade-connected dual triode.) The distortion of the cascode 8SN7 with 5V RMS output signal (no feedback and not connected to the inverter) is less than 0.3% from 30Hz to 20kHz. The long-tailed phase inverter using a push-pull 8SN7 offers reduced phase shift and a stable feedback loop by eliminating a stage of amplification.

The long-tailed phase inverter has unequal output voltages due to the slightly higher gain of the grid-driven section. Balance of these sections is obtained by shunting the 47kΩ resistor (R9) with a 470kΩ resistor (R12). The balance was maintained with five different 8SN7s, so this should provide a permanent fix.

An anti-ringing R/C network (C4 and R21) is connected to the signal grid of the inverter. The distortion of the inverter stage, measured on either side (no external feedback and not connected to the KT-88s), is less than 0.3% from 30Hz to 20kHz at 45V RMS output. Allowing for the push-pull effect and resulting harmonic cancellation, the total harmonic distortion for the inverter can be assumed to be approximately 0.2%. The frequency response of the driver stage (8SN7) and inverter (8SN7) with feedback applied is flat from 20Hz to 35kHz. The 45V RMS drives the push-pull KT-88s to their rated output of 70W.

PHOTO 2: Underside of amplifier.

FIGURE 1: Amplifier schematic.



OUTPUT STAGE

The KT-88 output tubes operate at 70W class AB1 under conditions shown in *Table 2*. The fixed-bias voltage on the grids of the KT-88s is –65V DC, and no clipping occurred at the 70W level. You obtain the KT-88 static plate-current balance by adjusting the 25kΩ balance control (P11) in the grid circuit of the output tubes. Balance is obtained when a minimum voltage differential (approximately 0V DC) exists between the KT-88 cathodes (TJ-1 and TJ-2).

If you have a distortion meter, I suggest you adjust the balance control for minimum distortion at 35Hz. To ensure balance, use matched KT-88s. I recommend ordering four KT-88s, all matched.

To assist in the balancing of the KT-88s, I inserted a 1.0Ω resistor in the cathodes of each KT-88. You set the plate current by adjusting the bias-voltage potentiometer P1/P2 (*Fig. 2*). A static plate current of 130mA is the correct operating current for the push-pull KT-88s, and no color on the plates is evident at this level. A 1.3V DC indication at TJ-3 and TJ-4 corresponds to a 130mA plate current. The resistors connected to the control grids and screen grids of the KT-88s are required to prevent oscillation of the output tubes.

Caution: Before applying plate voltage to the amplifier, make certain you've wired the grid circuit properly and the required –65V DC is present on the control grids of all four KT-88s.

You must connect the inverse feedback circuit (R28B and P27) to the 4Ω secondary winding tap of transformer (TR1) when using a 4Ω speaker. When using an 8Ω speaker, you must connect the inverse feedback circuit (R28A and P27) to the 8Ω secondary winding tap of transformer (TR-1).

The secondary windings of the Hammond output transformer must be connected in a series configuration as shown in *Fig. 1*. If oscillation occurs when the amplifier is turned on, reverse the primary plate and screen leads of the output transformer. NOTE: Use inexpensive speakers when the amplifier is initially turned on. Always have a load on the secondary outputs of transformer TR-1.

AMPLIFIER POWER SUPPLY

The circuit diagram of the power supply is shown in *Fig. 2*. The Hammond plate-supply and filament transformer is available from Antique Electronics Supply. The bias transformer and asso-

TABLE 1
AMPLIFIER PARTS LIST

Note: All parts are available from Radio Shack, Radio Shack DOT COM, or All Electronics

C1, C2	1μF, 250V, metal film	RS 272-1055
J1–J6	Female, phono jack, chassis mount	RCMJ ALEL
*S1	Switch, 2 pole, 6-position, switch	RS 275-1386
P1	100k, 0.5W, pot, audio taper	900-7920 R S DOT COM
R8, R19	18k, 2W	900-0848 R S DOT COM
R9, R10	47k, 2W	900-0858 R S DOT COM
P11	25k, 0.5W, linear taper	900-7908 R S DOT COM
R20	4.7k, 5W, W.W.	900-0984 R S DOT COM
R24, R25	270Ω, 2W, M.O.	900-0804 R S DOT COM
*P27	50k, 0.5W, dual, linear, taper	900-7940 R S DOT COM
R29	34k, 4W; parallel two 68k, 2W resistors	900-0862 R S DOT COM

Note: The Radio Shack DOT COM 2W resistors are used because of their larger size, as compared with other 2W resistors.

Note: The following are available from Antique Electronics Supply, except as noted.

C7, C8	50μF/50μF, 500V, C-EC-50-50-500; mounting bracket, S-H122
C4	150pF, 500V silver mica
C5, C6	0.15μF, 600V, polypropylene, Orange Drops
C3	250pF, 500V, silver mica
R2–R6	820Ω, 1W, carbon
R7	1M, 1W, carbon
R12	470k, 1W, carbon
R13, R14	82k, 1W, carbon
R15, R16	220k, 1W, C.F.
R17, R18	2.2k, 1W carbon
R21, R28B	10k, 1W, metal film
R28A	15k, 1W, metal film
R22, R23, R26	1.0Ω, 1W, M.O.
T1	Hammond, 100W, primary 5kΩ, ct, sec. 4, 8, and 16Ω, P-T1650R
V1, V2	8SN7 (NOS)
*V1S–V9S	octal socket
TJ1–TJ4	Insulated Tip Jack S-H260/S-H261 (4 red, 4 black)

Note: All following parts are available from Part Express.

SPT1	Speaker output terminal, 4 output, 260-305
V3, V4	KT-88, Sovtek (matched quad)

All parts are doubled for stereo, except those preceded by an asterisk.

POWER SUPPLY PARTS LIST

M1	120V AC 4" fan RS273-241 (optional)
T1	6.3Vct, 4A, AES, P-T166N6
T2	25.2Vct, .450A, R.S. 273-1366
T3	800Vct, 0.465A, 6.3Vct, 6A Hammond, A.E.S. P-T 278CX
C1	4700μF, 16V, RSU11935095
C2, C3	2200μF, 50V, R.S. 272-1048
C4, C5	820μF, 350V DC (connect in series), EC-8235 ALEL
C6, C7	0.05μF, 1600V, A.E.S. C-SD05-1600
C8	0.1μF, 600V, A.E.S. C-SD1-600
D1, D2	3A, 50V, RS 276-1741
D3–D6	3.0A, 1000 P.I.V., 900-2882 R S DOT COM
BR1	1.4A, 100V R.S. 276-1152
P1, P2	Potentiometer, 25k, linear, 0.5W 900-7908 R S DOT COM
R3, R4	100k, 1W, AES
R5, R6	Resistor, 27k, 10W, wire wound 900-1131 R S DOT COM
Fuse holder	P.E. 071-510
F1	Fuse 3AG, 5A, slow-blow, P.E. 071-706
S1	Switch, S.P.S.T., P.E. 060-370
AC cord	6', R.S. 278-1258B
Terminal strip	5 lug, R.S. 274-688 (3 packs)
Chassis	17 × 10 × 3, A.E.S., P-H1441-32
Rubber feet	(4) AES P-H253

R.S.=Radio Shack
Radio Shack Dot Com, 1-800-442-7221
A.E.S. (Antique Electronics Supply), 6221 South Maple Ave., Tempe, AZ 85283
P.E. (Parts Express) 1-800-338-0531
ALEL=All Electronics 1-800-826-5432

ciated circuitry are available from Radio Shack. Many of the discrete components are available from Parts Express and All Electronics.

The bias supply (–70V DC) uses transformers T2 and full-wave bridge rectifier BR-1. Capacitors C2 and C3 supply voltage doubling. Potentiometer P1/P2 sets the bias to the KT-88s at approximately –65V DC.

The 6.3V/4A center-tapped filament transformer is connected to a full-wave rectifier (D1/D2) and capacitor (C1) and provides 8.4V DC (0.6V RMS, ripple) to operate the four 8SN7s heaters. A 4A transformer is required to obtain the 8.4V DC output. I recommend that you mount the transformer on the side of the chassis and not directly beneath the H.V. transformer as shown in the photo. The power transformer's high-voltage winding feeds a full-wave diode bridge rectifier (D5/D6) and (D4/D3) and provides a +540V DC output with the amplifier's output at 70W. The center-tapped low-voltage winding provides 6.3V AC to operate the four KT-88 heaters.

The series bleeder resistors (R5/R6) are used primarily to protect the electrolytic capacitors. Capacitors C6, C7, and C8 eliminate AC hash. The AC ripple of the 540V DC output of the power supply is 1.6V.

TABLE 2
TUBE DATA FOR ULTRALINEAR MODE

KT-88	(PUSH-PULL, AB1)	INVERTER	(LONG-TAIL)	DRIVER	(CASCODE)
Ebb	550/540V DC	Ebb	445V DC	Eb2	248V DC
Eg2	550/540V DC	Eb1	306V DC	Eb1	124V DC
Eg1	–65V DC	Eb2	302V DC	Ek2	127V DC
Ib no signal	2 × 65mA	Eg1	127V DC	Ek1	3.4V DC
Ib max signal	2 × 125mA	Eg2	118V DC	Ec2	124V DC
P+G2 Diss. (zero signal)	2 × 34W	Ek1 + Ek2	134V DC	Ec1	0V DC
P+G2 Diss. (max. signal)	2 × 35W	Ib1	3.4mA	Ik1	3.6mA
RL p-p	5kΩ	Ib2	3.6mA		
Dist. @ 1kHz	1.8% (no feedback)				
Power output	70W				

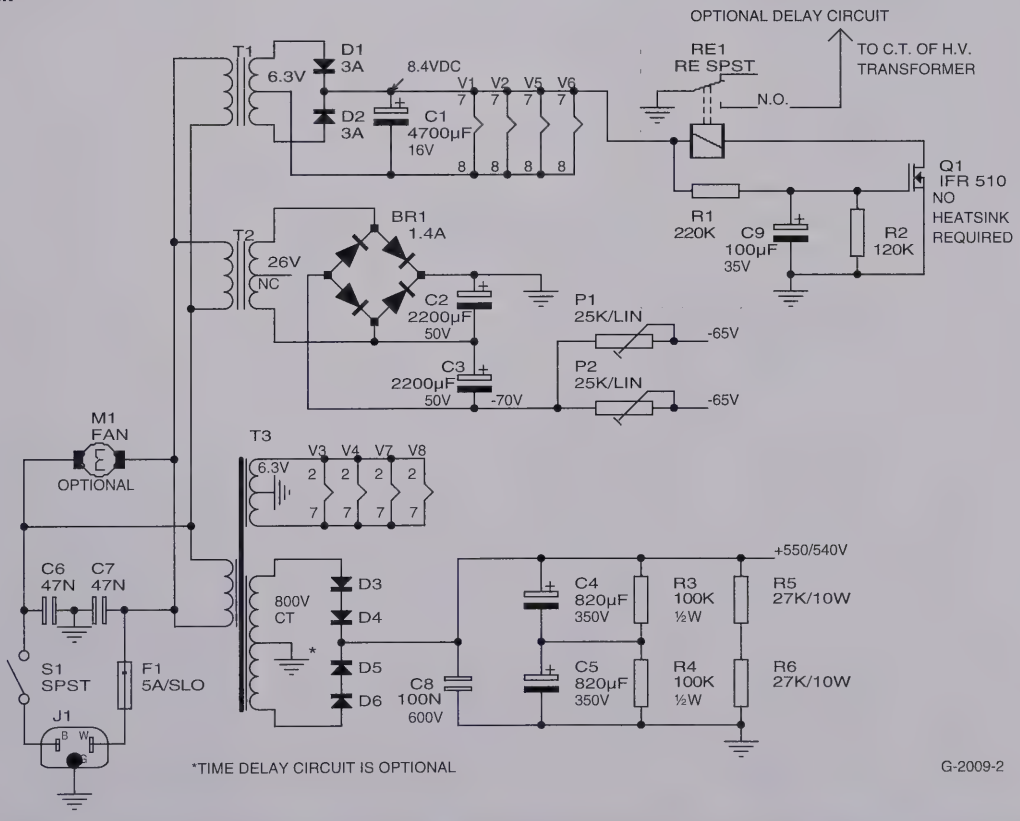
TIME DELAY TURN-ON CIRCUIT (OPTIONAL)

A simple, inexpensive, 20-second time delay is shown in the *Fig. 2* schematic. This time delay circuit uses a relay RE1 (RS 275-005A), switching MOSFET

TABLE 3
HARMONIC DISTORTION DATA %

	10W	20W	40W	60W	70W
30Hz	0.18	0.32	0.74	1.0	1.15
100Hz	0.16	0.28	0.62	0.7	0.88
1kHz	0.14	0.26	0.6	0.7	0.8
10kHz	0.14	0.26	0.66	0.74	0.84
15kHz	0.2	0.32	0.68	0.9	1.0

FIGURE 2: The power supply's circuit diagram.



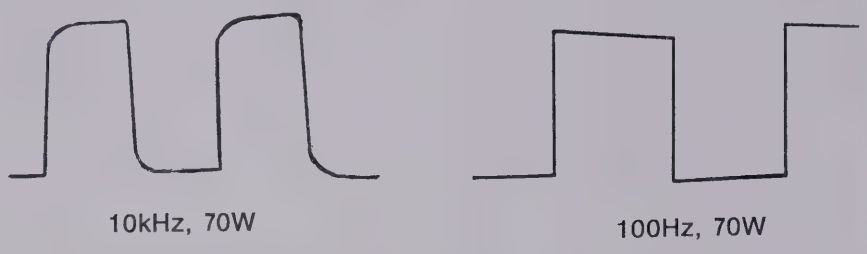


FIGURE 3: Square-wave oscillograms for the 70W UL mode with 8dB global feedback applied.

IRF510, and R/C timing network, consisting of R1 (220k, ½W) and capacitor C9 (100µF, 35V). You increase or decrease the delay time by changing the value of R1. The decay time is hastened by resistor R2 (120k, ½W) when power is removed from the timing circuit. A heatsink is not required for IRF510.

Note: When the IRF510 is switched on, after 20 seconds, expect +3V DC at the junction of C9 and R2 and 0.1V DC at the drain of IRF510. The power to operate the relay and timing circuit is obtained from the 8.4V DC power supply used to power the 8SN7s heaters. When the timing circuit is added to the amplifier, connect the N.O. relay contact to the H.V. center-tap winding of the high-voltage transformer.

The timing circuit is an optional addition and is not a circuit requirement of the 70W amplifier. All parts are available from Radio Shack. [The 20-second delay will, however, extend the life of your output tubes since they are fully heated and ready for full power after 11 seconds.—Ed.]

AMPLIFIER PERFORMANCE CRITERIA

The performance data of the amplifier is presented at its maximum operating levels. At 1 and 10W, from 30Hz to 15kHz, the distortion is less than 0.14% and 0.18%, respectively. The harmonic distortion data is presented for 10, 20, 40, 60, and 70W operating levels (*Table 3*). I made the amplifier distortion measurements using the 8Ω output taps. The distortion measurements for the 4Ω output mimic the 8Ω distortion readings.

The square-wave oscillograms (*Fig. 3*) are shown for the 70W output of the amplifier. The 100Hz and 10kHz square waves exhibit slight low- and high-frequency rolloff, while the 1kHz square-wave is reproduced almost perfectly. No high-frequency ringing occurred with the amplifier reproducing the 10kHz squarewave, even with a 0.1µF capacitor shunted across the transformer secondary—indicating good high-frequency stability.

The amplifier is also stable at low frequencies. At 70W the frequency response is flat from 30Hz to 15kHz. The maximum inverse (negative) feedback of the amplifier is approximately 8dB. The noise, measured with the input open, is 1.4mV at the 8Ω taps (3.4mV—no feedback).

In conclusion, the performance specs speak for themselves. Here is an amplifier that you can build for moderate cost, while encountering few construction problems.

CONSTRUCTION TIPS

- I used point-to-point wiring. Most components are tied to the five-pin terminal strips; the center terminal is ground, and components requiring a ground are tied to this ground post.
- You may cut the primary windings of the output transformer to shorten the plate leads.
- The secondary windings of the output transformers are stripped and soldered, and I recommend that you not cut and restrip them. The preferred method is to snake them around the output transformer's 10-32 holding screws and secure the wires with cable clamps and 10-32 nuts. All the transformers are secured with 10-32 fasteners.
- The output of the inverters coupling capacitors are connected to the grids of the KT-88s via a shielded cable, which is grounded at both ends. (CAUTION: Make certain the shield of the cable is not shorting the center conductor, as damage to the output tubes would occur).
- The bias supply requires two terminal strips and the filament transformer requires one. Six additional terminal strips are located throughout the amplifier.
- A short ground path is provided for the ringing, grid, and cathode circuits of the 8SN7s' grid and cathode circuits. You must ground (at both ends) the five-conductor shielded cable connecting J1–J6 to the six-position S1A/B. Also connect a shielded cable from the output of S1 to R1.
- Use mounting feet on the bottom of the amplifier chassis to give good under-chassis airflow. The power transformer, although operating within its recommended limits, "runs" very warm to hot, and if this is a problem, I suggest you install a fan (Radio-Shack 273-241) in the cabinet housing the amplifier.

Distortion (no feedback) @ 1kHz: 3W, 10W, 20W, and 70W is 0.5%, 0.6%, 0.9%, and 1.8%, respectively.

Warning: Lethal voltages are present, exercise extreme caution when constructing the amplifier and never leave the amplifier upside down when children are present. ❖

TEST EQUIPMENT USED

H-P 331A distortion analyzer
Oscilloscope, Protek 650
Heath sine/square audio generator, IG-5218
DMM Radio Shack 22-168A

ACKNOWLEDGEMENT

I built this amplifier for the love of my life—my daughter, Pamela M. Sill

www.audioXpress.com

A 45 SE Inductor Coupled Amp

This triode-based design calls for inductor coupling and biamplification.

By Barney Vincelette

In designing and building this amplifier (*Photo 1* and *Fig. 1*), I was interested in musical refinement above all other considerations. (See parts list in *Table 1*.) It had to have the richest and smoothest sound possible. For this, nothing can match a 45 single-ended triode amplifier. But you must pay a price for the lyricism and richness that only a 45 can produce.

It has feeble output power and poor bass response. I would need to run a powered subwoofer with the system. (Fortunately, the line-level signal to the 45 amplifier would not need to go through the high-pass filter in the subwoofer's solid-state electronics.) It would require efficient speakers, preferably with biamplification between the tweeters and the midrange, and it would need to be used in a limited size listening chamber with not too much distance from the speakers to the listening position.

DRIVER SELECTION

I chose G.R. Research for the speakers, and the company recommended

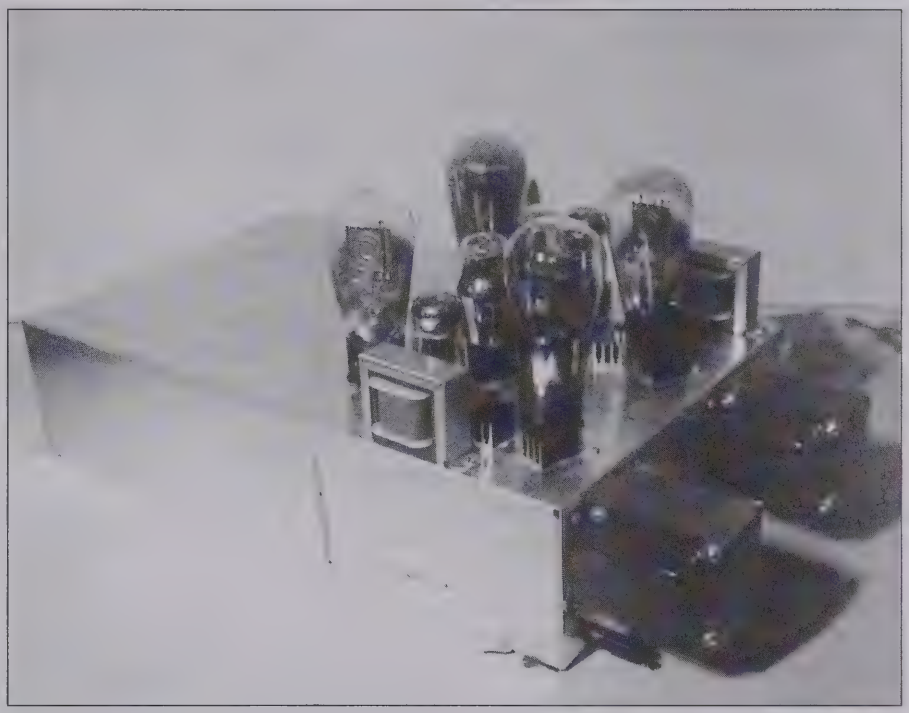


PHOTO 1: The 45 amp. Note the two monoblock biamplifiers in one chassis.

TABLE 1
AMP PARTS LIST

QUANTITY	REFERENCE	PART
2	C1, C6	220µF
2	C2, C7	4µ7
6	C3, C4, C8, C9, C11, C14	100N
1	C5	15µF
2	C10, C13	47µF
1	C12	100µF
1	K1	RCA jack L.-IN
1	L1	75–100H
3	RA1, RA2, RA24	Attenuator resistors
2	R1, R4	1k
1	R2	47k
1	R3	100k
4	R5, R6, R7, R8	7k5
1	T1	8:1 600Ω out
2	T2, T3	5k
1	V1	6P5 or 76 or 6J5
1	V2	6SN7G
2	V3, V4	45 or 245

ABOUT THE AUTHOR

Dr. Vincelette began his hobby of tinkering with vacuum tubes as a teenager when he built transmitters he put in cars. He went into the Air Force, where he worked for a time as a C 130 navigator sometimes in Vietnam, where he earned a Distinguished Flying Cross and three Air Medals. He also graduated from Electronics Warfare Officer School and Electronics Communications Systems Officer School at the front of his class. After leaving the Air Force he worked as an aircraft mechanic, an air taxi pilot, and a flight instructor. He also attended graduate school part time, eventually earning two Masters degrees from Delaware State University and a PhD in physics from Columbia Pacific University.

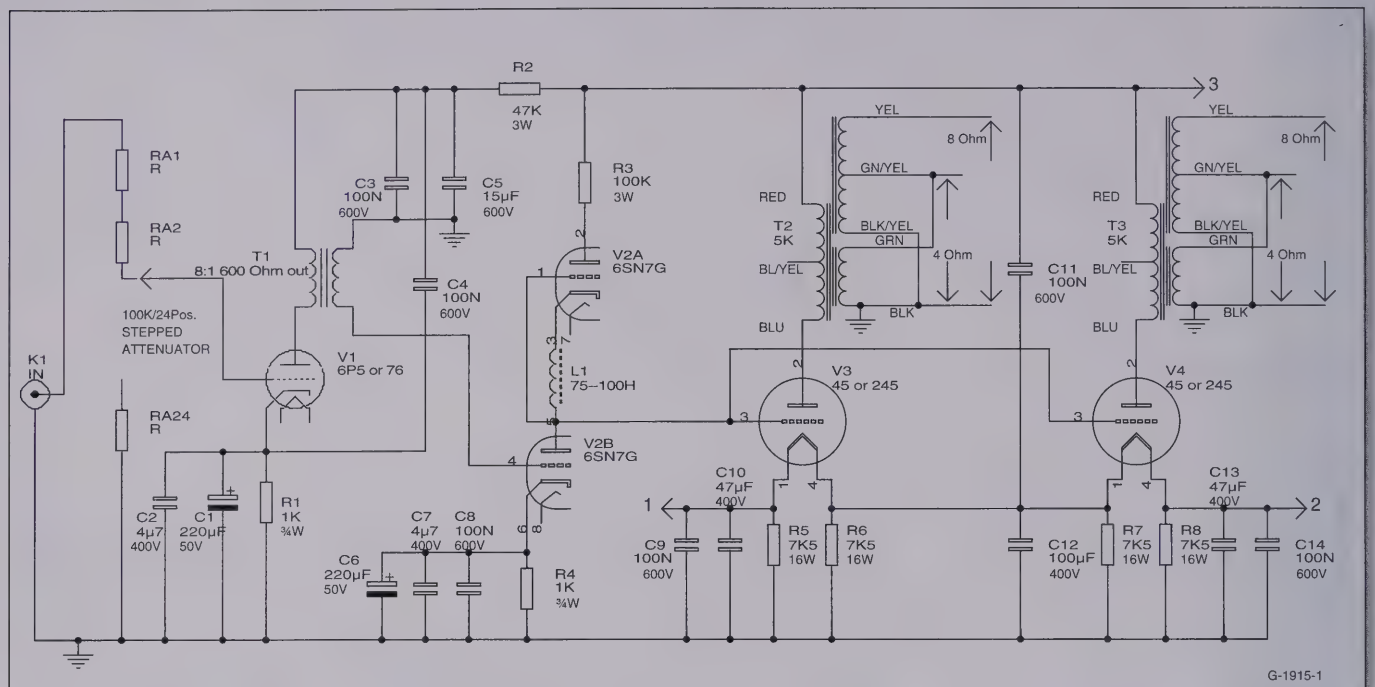


FIGURE 1: SE 45 Amp.

a pair of GR-130 midrange drivers and a Raven R-1 ribbon tweeter in a D'Appolito array. You can biamplify these drivers, which use no resistors in the signal path.

Each midrange pair and each tweeter would have its own output transformer and 45 triode. Since both outputs would use an identical signal, you could connect both transformers to the same DC power supply, and both 45s could have their grids connected to the same driver (*Fig. 2*). Thus the 45s would act as buffers thereupon introducing an element of polish to this design. No back emf from one speaker or crossover would get into the other.

DESIGN CONCEPTS

For the driver I wanted the clear and pure sound that a choke-loaded plate such as described in Jack Elliano's article, "Direct Reactance Drive Amplifier" in *Vacuum Tube Valley* Issue 14, would offer. But at low frequencies the plate choke has so little reactance that it will add more rolloff to the bottom of the audio spectrum. A mu follower used a plate resistor that I did not like. But the flat frequency response of a mu follower was also desirable.

István Béri presented a most interesting choke-loaded mu stage in his article, "The Tradition: A Triode Odyssey" in *Glass Audio* 6/00. With a modicum of modification, in particular, the introduction of cathode grounding capacitors C6, C7, and C8, the lower plate of V2 would have a low enough output impedance to drive both 45 grids. At low frequencies, the upper element of V2 would by force and effect multiply the reactance of inductor L1.

So I called Electra-Print Audio and proprietor Jack Elliano to ask him whether he thought it would work. He said that he did not have time to test it, but he offered me a pair of chokes with the approximately 1kΩ DC resistance needed to bias the upper cathode of V2 and an inductance somewhere between 75 and 100H. In exchange for these chokes, I agreed to test the low-frequency response of a pure choke-loaded plate, and that of the inductive mu stage and report the results to him and publish an article about it.

I used the *Hi Fi News & Record Review* test disc to measure the AC voltage on the grids of the 45s at different frequencies. With the choke only, the

TABLE 2
POWER SUPPLY PARTS LIST

QUANTITY	REFERENCE	PART
1	BT1	Battery 12V lead acid
4	CR1, CR2, CR3, CR4	FREDs (Fast Reacting Expietial Diodes) Motorola MUR 860
1	C15	15µF Solen
2	C16, C19	100N film foil
2	C17, C18	220µF Mallory
2	C20, C21	100µF Solen
3	C22, C23, C24	50mF (millifarads) Mallory
1	F1	3A Slo Blow
1	F2	½A Slo Blow
1	J1	AC IN
3	L2, L3, L4	5H Hammond 193H
2	L5, L6	4mH 16GA wire LS inductors, Parts Express #206-405
1	R9	0.47 5W
1	R10	20Ω 5W
1	S1	SPST
1	S2	DPST
1	T4	Hammond 272FX
1	V4	GZ37

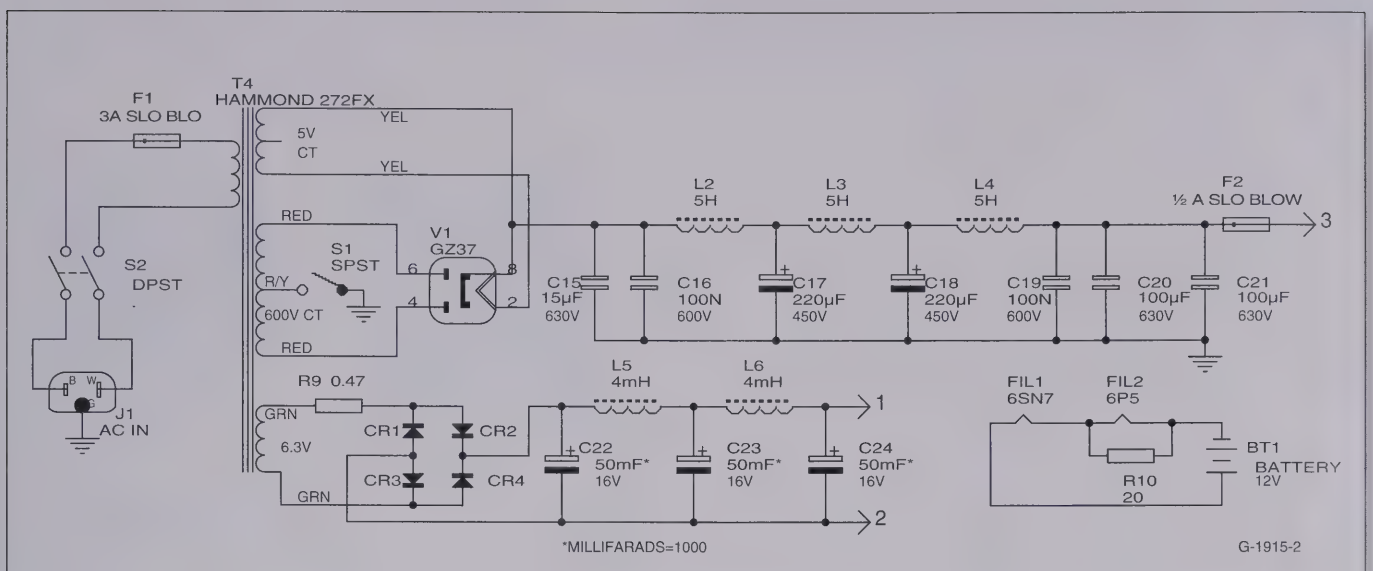


FIGURE 2: Power supply.

voltage on the grids was between 58 and 60 in the frequency range of 400Hz through 20kHz. With the choke loaded mu stage, it was between 58 and 60 from 10Hz through 20kHz.

In both cases the use of a choke made smoother and clearer sound than the resistor-loaded mu follower. But at 40Hz the choke-only load put only 45V on the 45 grids. I chose the choke-loaded mu stage.

Finally, I needed a line stage to give the amplifier appropriate sensitivity. In the autumn 1999 issue of *Listener*, the editors described a line-stage preamplifier using a 76 triode and an interstage transformer as revolutionary in that it surpassed every preamplifier they had ever heard before. It was also considered perfect for a 45 S.E.T. amplifier. It was designed from the works of Bruce Berman in *Sound Practices* (issue 13), Jack Elliano in *Vacuum Tube Valley* (issue 10), and Eric Barbour's *Glass Audio* work by Jeff Korneff in Pittsburgh. So I followed the design, but used the 6P5, which is a 76 with an octal socket. Some people prefer the more lively sounding 6J5 which will also work here without need for circuit modification.

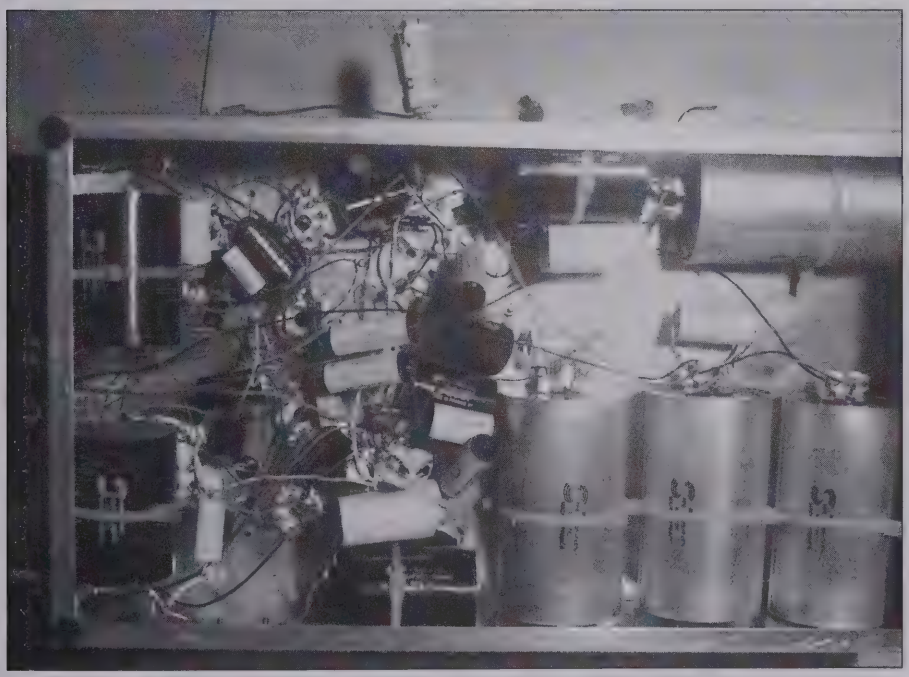


PHOTO 2: Underneath view of amp.

SUMMARY

How does the finished project work? It sounds much more like a live concert than any of the five-figure-priced amplifiers I have heard in the audio salons. Brass and cymbals sound metallic and clear. You can hear the wood and varnish in the string instruments as never before. In short, it has exceeded my every expectation. Visitors who hear it are always astonished.

I have two recommendations for anyone who builds this amplifier: First, put the amplifier itself and the power supply (*Photo 2*, see parts list, *Table 2*) in separate chassis. Second, have the interstage transformer T1 as far away from power transformer T4 as practical. ❖

SOURCES

G.R. Research
2412 10th St
Wichita Falls, TX 76309
940-723-7900
FAX 940-723-2266

Electra-Print Audio
4117 Roxanne Dr.
Las Vegas, NV 89108
e-mail electaudio@aol.com
702-396-4909
FAX 702-396-4910

A Hybrid Tube Radio

Build your own music box, incorporating source, amplifier, CD, and speaker in one chassis. **By David Wang**

PHOTO 1: A three-in-one music box.

Have you ever been captivated by music playing in the background? A small table radio or jam box playing in the office or garage while you toil away on some task causes you to stop what you are doing and makes you listen to the music. Why is it that these small devices can still portray the beauty of music? Is it because you are just listening to the music and not worried about the sound? Who knows!

REQUIREMENTS

With this in mind, I wanted to make something better than the off-the-shelf jam box or table radio. The device needed to be small (less than $1ft^3$), portable, easy to use, and attractive (this could be subjective). Most importantly, all three aspects of an audio system needed to be contained in this box: the source, the amplification, and the speaker (*Photo 1*).

In keeping with the spirit of the project (and keeping it simple), I decided to use a mono speaker system. This way, there only needs to be a mono amplification device. I chose a CD player as my source because the majority of my music collection is on compact disc. And finally, as a vacuum tube enthusiast, I wanted to use a tube amplification circuit.

I believe that this is a project for a novice electronics assembler with advanced sheet-metal or woodworking skills. The most difficult part of the project is manufacturing the chassis. I chose to use sheet metal because I have access to sheet-metal folding and cutting equipment. I lack woodworking skills, so fabricating the chassis out of wood was out of the question, although I do believe that you might obtain better results with a wood chassis, especially in the speaker box.

The CD player is actually a CD-ROM drive. I found this to be the perfect device because of cost, size, and function. You can find relatively inexpensive CD-ROM drives at discount computer-supply stores or, in my case, eBay. Using a CD-ROM drive simplifies things tremendously.

Be sure to find one that has both a play and a skip button. Some have only a play button, which will keep you from being able to skip tracks. You can use either the headphone jack or the audio

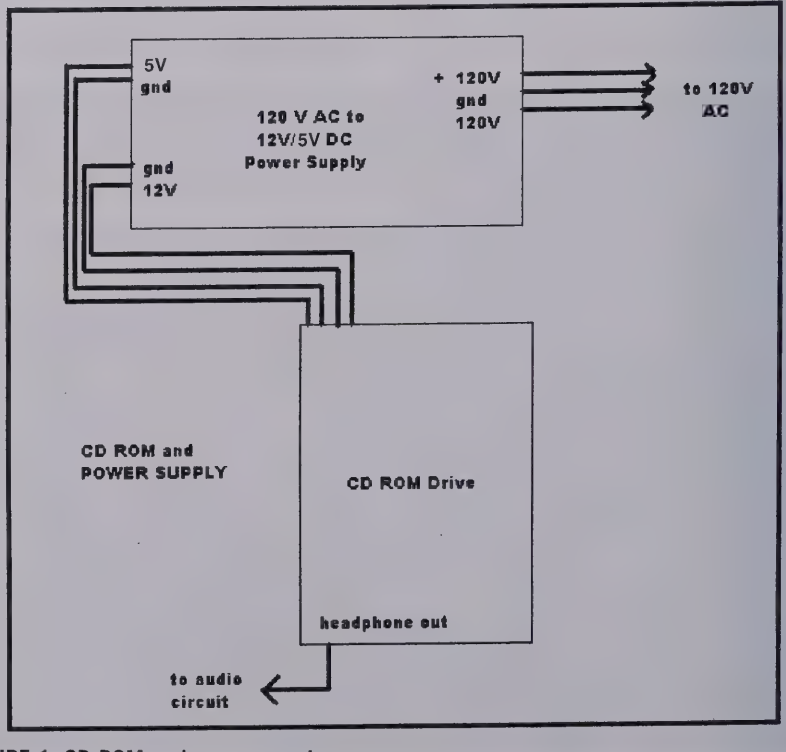


FIGURE 1: CD-ROM and power supply. G-1807-1

ABOUT THE AUTHOR

David Wang obtained a Bachelor of Science Degree in Computer Science from the University of Texas at Austin in 1997. He worked for several years in the computer industry specializing in test development. Since August of 2001, he has been living in New York City pursuing a career in [illegible]. He can be reached at [illegible]

out jack in the rear of the unit. With the headphone jack, you can use the volume control on the front of the unit. Otherwise, you will need to install a volume pot. A 120V AC to 12V/5V DC dual power supply powers the drive (*Fig. 1*).

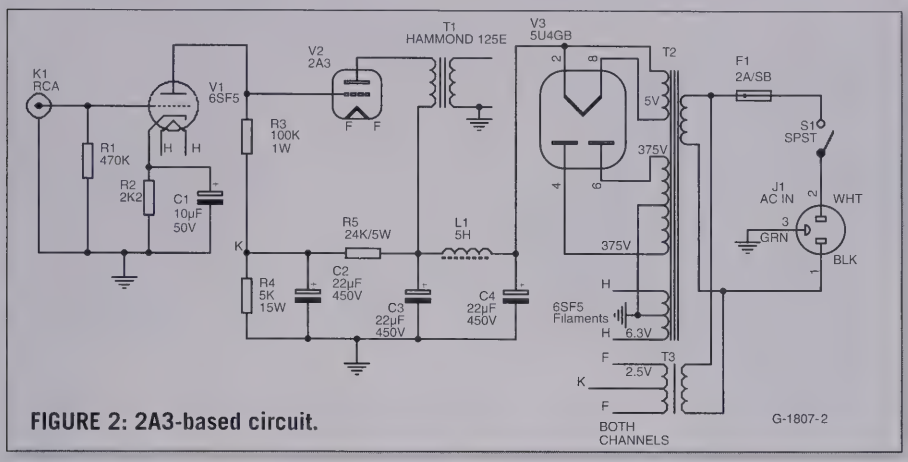


FIGURE 2: 2A3-based circuit.

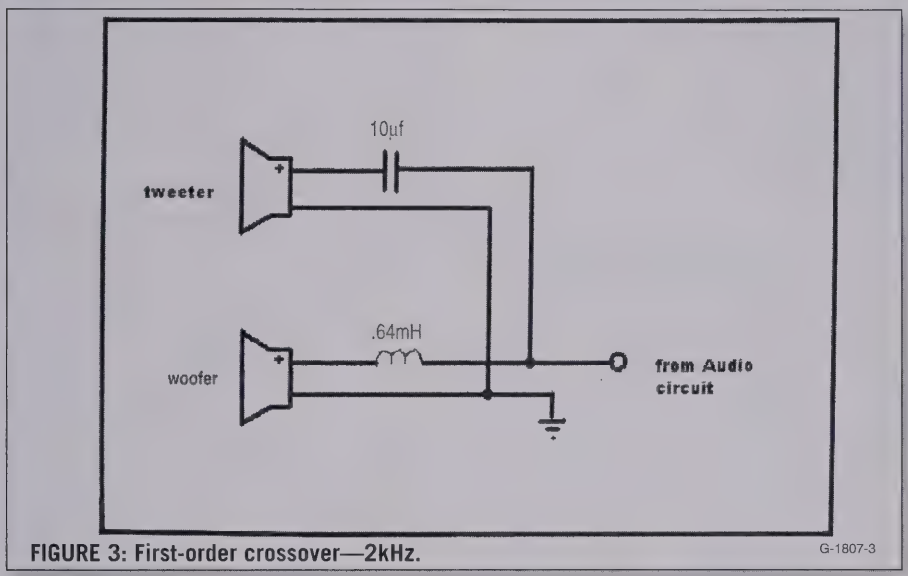


FIGURE 3: First-order crossover—2kHz.

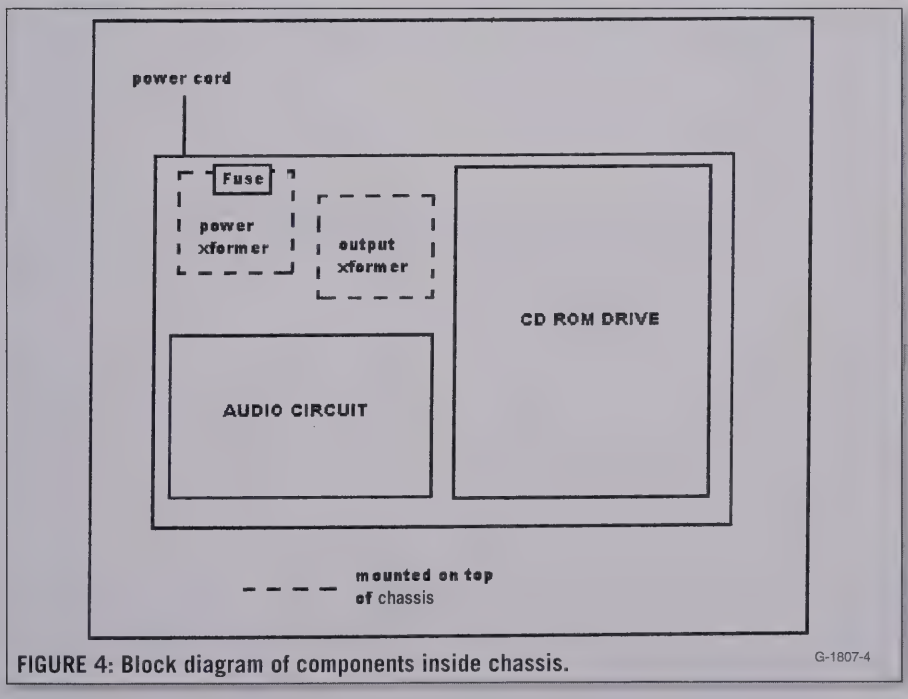


FIGURE 4: Block diagram of components inside chassis.

Recently I have been listening to single-ended tube circuits, which I find can really capture the magic of music. Single-ended tube circuits are also very simple to build and require fewer parts. I chose a 2A3 powered circuit, which I modified from a designer who chooses to remain anonymous (*Fig. 2*). It sounds quite nice so I decided to use it in my project. *Table 1* shows the parts list.

Of course, you can use any circuit you wish. There are many good circuits to be found on the Internet. I suggest that you find a 2A3 or 300B single-ended circuit. For more power, a push-pull EL84 circuit is an excellent choice.

Because my amplifier section puts out only about 3W, I needed to build a speaker with high sensitivity. I had never built a speaker before, so I undertook some research on crossover design. I decided to use a first-order crossover (*Fig. 3*).

I chose relatively inexpensive drivers from Audax. The tweeter is an 8Ω 14mm polymer dome tweeter (Audax TW014F1), and the woofer is an 8Ω 4″ paper cone mid/bass driver (Audax HM100G0). Sensitivity turns out to be about 90dB—not the most efficient design, but it works well with vocals and small-scale music. I will probably increase the efficiency in future designs.

CONSTRUCTION

I used a sheet metal brake and corner cutter to construct the chassis using 16-gauge aluminum sheet metal. I didn't have any special tools for cutting the holes for the speaker drivers. I just drilled many holes along the circumference of the hole and then cut the little spaces between each with wire cutters.

I did the same for the CD player drawer hole. I made the holes for the tubes with a Greenlee hole punch. After making all the necessary holes, I then sanded, primed, and spray-painted the chassis with enamel paint.

I purchased plastic buttons for the CD-ROM drive through Mouser Electronics. These have a small screw on the inside, which I screwed into the plastic "straw" found in a disposable ball-point pen. I then inserted them into holes drilled at the same location of the buttons on the CD-ROM drive; they were held in place by friction.

This could use some re-engineering, but it is functional.

You can skip this step altogether and have the entire front panel of the CD-ROM drive showing, but I chose to keep it hidden. I machined my own brackets for mounting the CD-ROM drive, which already has screw holes for mounting into a computer. The tricky part is aligning the drive with the drawer and button holes drilled in the chassis.

I tried to keep things organized on the inside of the chassis to help reduce hum (*Fig. 4*). Be sure to twist all AC wiring, especially the wire going to the power supply for the CD-ROM drive. Also, take care to keep the wires going from the output transformer to the speaker drivers away from the AC wiring that goes to the CD-ROM power supply (*Fig. 5*).

One of the major challenges in this project is keeping vibration from the speaker system to a minimum (*Fig. 6*). The major problem with using metal as a speaker enclosure is that vibrations will cause an audible ring. To combat this problem, I lined the entire speaker enclosure with Soundcoat, a self-adhesive vinyl damping material available through Parts Connexion. I also used this inside the chassis and on the bottom of the CD-ROM drive.

I believe this project is a wonderful exercise in many aspects of the DIY audio hobby. You are really designing a complete audio system packaged in a small box. I encourage those who only build amplifiers to attempt to build a speaker, and vice versa. ❖

TABLE 1
PARTS LIST

AMPLIFIER SECTION
(1) 470k 1W resistor (AES R-B470K)
(1) 2.2k 1W resistor (AES R-B2D2K)
(1) 100k 1W resistor (AES R-B100K)
(1) 5k 15W resistor (MOU 284-HS15-5KF)
(1) 25k 5W resistor (AES R-Q25K)
(1) 10µF 50V capacitor (AES C-ET10-50)
(3) 22µF 450V capacitor (AES C-ET22-450-105)
(1) Hammond 158Q 5H/150mA choke (AES P-T158Q)
(1) Hammond 125E universal output transformer (set to 3k secondary) (AES P-T125E)
(1) Hammond 274BX (375-0-375) power transformer (AES P-T274BX)
(1) Hammond 166M2 2.5VCT filament transformer (AES P-T166M2)
(1) Tube socket, 4 pin (AES P-ST4-205M)
(2) Tube socket, octal ceramic (AES P-ST8-801)
(1) 6SF5 triode (AES T-6SF5)
(1) Sylvania 5U4GB (TRI 5U4-GB)
(1) Sovtek 2A3 (TRI 2a3sovtek)
(1) 2A slowblow fuse (MOU 504-MDL-2)
(1) Fuse holder (MOU 441-FH001)
(1) IEC socket (MOU 161-0707-1)
(1) On/off switch (MOU 103-2031)

CD SECTION
(1) Acer 40X IDE CD-ROM drive (BUY 91.AB264.043)
(1) 12V/5V DC power supply (MOU 552-PSA-25L-201)
(4) CD-ROM buttons (MOU 633-AT407(A/B/C))
(1) Headphone cable (MOU 172-2206)

SPEAKER SECTION
(1) Audax woofer (HM100G0) (MAD HM100G0)
(1) Audax tweeter (TW014F1) (MAD TW014F1)
(1) 10µF capacitor (Solen) (WEL SOL16)
(1) .68mH inductor (Alpha-Core) (WEL ACO.68)

MISCELLANEOUS
(2 sheets) SoundCoat (SFI 55503)

COMPANY KEY
AES—Antique Electronics Supply
www.tubesandmore.com
BUY—BUY.COM—www.buy.com
MAD—Madisound Speaker Components, Inc.
www.madisound.com
MOU—Mouser Electronics—www.mouser.com
SFI—Sonic Frontiers International (Parts Connexion)
www.sonicfrontiers.com
TRI—Triode Electronics—www.triodeel.com
WEL—Welborne Labs—www.welbornelabs.com

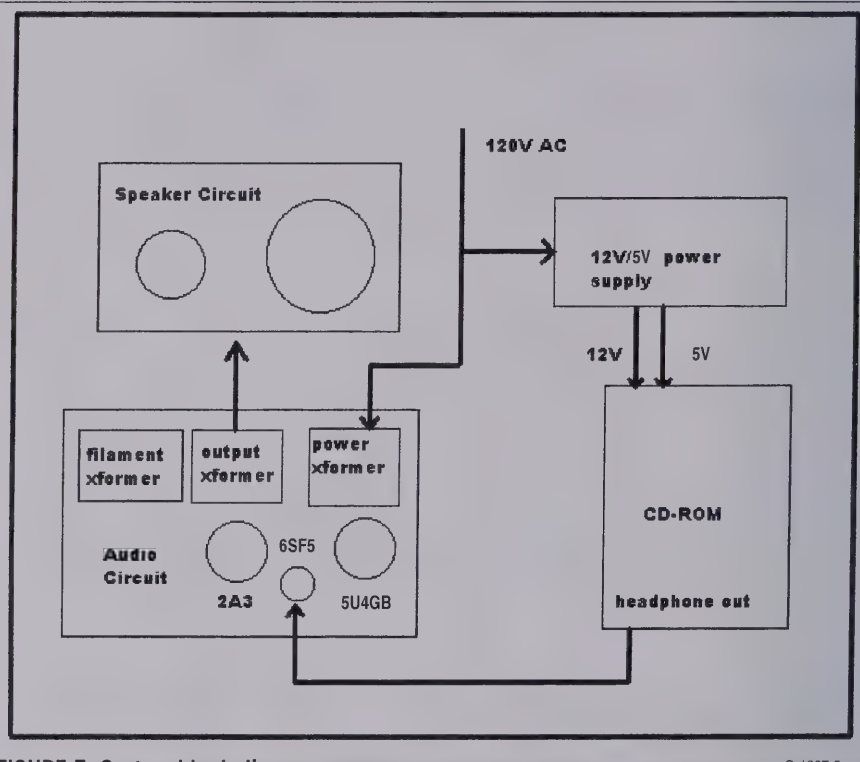


FIGURE 5: System block diagram.
G-1807-5

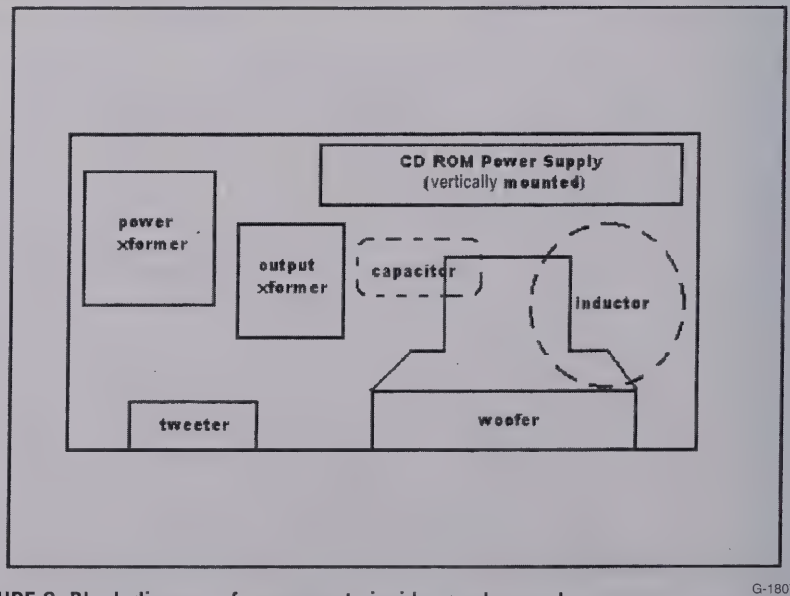


FIGURE 6: Block diagram of components inside speaker enclosure.
G-1807-6

The Direct-Coupling Modulated-Bias Circuit

As this author proves, sometimes simpler is better when designing a tube-amp circuit. **By Ari Polisois**

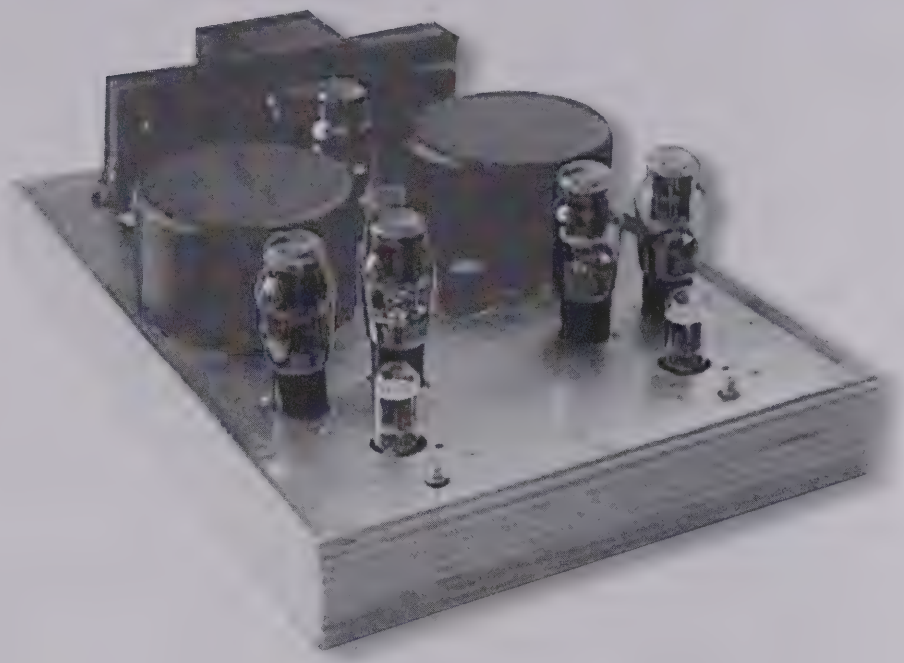


PHOTO 1: Amplifier with right and left channels on same chassis, using two 2A3s, paralleled, per channel, in a single-ended configuration.

There are many satisfactory direct-coupled circuits. Their sound is certainly different from the recurrent resistance/capacitance-coupled amplifiers, and it is not difficult to understand why. A capacitance introduces a time constant in the path of the signal and discriminates between the high and low frequencies. The result is a real mess. Phase shift, nonlinearity, intermodulation distortion, and lower slew rate are the known consequences. They are pitiless killers of high-fidelity reproduction.

Unfortunately, in a tube amplifier there is no way to get rid of the interelectrode and interconnection capacitances, so you must live with them. But some capacitors would better serve where they belong, i.e., bypassing the slow electrolytic types that, like the interelectrode capacitances, are a necessary evil.

A SIMPLE CIRCUIT

In trying to improve the concept of direct coupling, I worked out a circuit that is simplicity itself, the direct-coupling modulated-bias circuit (DCMB). *Table 1* is the parts list. The philosophical basis of the layout is that the shortest path is a straight line. In circuit A (*Fig. 1*), you see how complicated is the path of the signal coming from the driver and how many obstacles (its worst enemies, the capacitors) it must overcome before reaching grid and cathode of the power-amplification tube.

Instead (circuit B), the DCMB just crosses the street and reaches its target instantly and without losses (especially in the low-frequency end of the signal stream). It needs, as you will see, an additional power supply, but most of you will agree that quality deserves some sacrifices, and, after all, an additional power supply is not a big one. But the DCMB also has some hidden advantages that you will discover step-by-step.

To start your technical trip, *Fig. 2* shows a normal driver unit with two sections directly coupled to each other, as in Williamson's Concertina. But you will use only the upper output line, from the anode. I selected a popular tube, the 6SN7, with which I have performed hundreds of experiments. Its smaller brother, the 12AU7/ECC82, is also suitable and has even better characteristics if you wish to extend the range of the driver beyond 100kHz, an easy target for such a layout.

Observe the polarity of the voltage drop on the load (R5) of the driver's second section. Anything interesting? Not yet. But in *Fig. 3* the driver unit is now connected to the output tube. Thanks to the choice of using two independent power supplies (I was going to say "separated," but actually they are not, because the positive terminal of the driver's supply is connected to the negative terminal of the output tubes' supply), I can afford to connect the driver's anode to the grid of V2 without fear of causing a flow of current in it. Direct coupling? Yes, but also the best. I doubt whether you know anything simpler than this layout.

Now you don't need to bias V2 with a cathode resistor (bad for the damping factor) nor to use an external negative-

TABLE 1
PARTS LIST

R1	220k, ¼W
R2	160k, 1W
R3	1k, ½W
R5	8k2, 4W for 2A3s 12k, 6W for 300Bs
R6	12k, 30W, with heatsink
R7	±1k8, see text
R8	560Ω, ¼W
R9	1Ω, 2W
R10	47 to 100k, 6W, high-voltage, see text
R11	2k2, ¼W
C1, C2	450µF, 450–500V shunted with 47nF MKT or MKS capacitors
P1	2k2 linear potentiometer
OPT	PAT 3050-SE
V1b, V1a	6SN7 (or 12AU7-ECC82)
V2	Two 2A3s in parallel
P.S. "A-B"	350–400V @ 100mA for the two drivers' sections
P.S. "C-D"	260V (max. 270V) @ 200mA for each pair of paralleled 2A3s or 400V (max. 450V) @ 200mA for each 300B

voltage bias supply. R5 does the work, provided the voltage drop across the terminals of R5 corresponds to the required bias.

I should mention that, for the average-skill builder's use, the schematics comprise some incidental practical advice, certainly useless for those who are masters of the art of designing an amplifier. I refer, for instance, to the way of establishing the bias of the second section of V1.

THE FUNCTIONS OF R5

To summarize, R5 has three tasks: to act as the load for V1b, to act as the grid resistor for V2, and to provide for the bias of V2. Simple, isn't it? Too simple, unfortunately. As in the classic Concertina configuration, V1b has a high-value cathode resistor to compensate for the high voltage applied to its grid. Therefore, the amplification factor, which, as you know, depends upon the ratio anode load (R5)/cathode load (R7), is rather low. The solution could be to increase R5 or decrease R7.

You cannot increase the value of R5 because this would apply an even higher bias voltage to V2 than is necessary. In fact, it is already exceeded, because—if the plate current of V1b is set to 10–12mA—you build a drop exceeding 82V on the 8k2 resistor R5. I will return to this problem later.

Furthermore, you cannot decrease R7 without upsetting the balance between G2 and K2, which sets the bias voltage of V1b. Unless...

Figure 4 now shows the complete schematic. The role of R5 is now clear, and new components (shaded) have been added, each of them with a specific task.

Resistor R6 supplies extra current to R7, more than twice the plate current of V1b. R6 is a powerful resistor requiring a heatsink (better if on the top of the chassis or ventilated). Some may object that this means extra power consumption, but not many tube-amplifier audiophiles complain about the efficiency (seldom exceeding 20%) of the power triodes they use.

You must increase the current capacity of the drivers' power supply to 100–110mA. Then you can reduce the value of R7 to about one third, still keeping the voltage at K2 at the original level.

THE RESULTS

The effect is that the amplification of V1b is almost trebled. In addition, speaking in terms of alternating current, R6 shunts R7, thus further improving the gain.

Practical tests show that V1a (the first section of a 6SN7) amplifies about 12–13 times and the second section, after R7 is dropped to 1k8 (with R5 = 8.2k), almost four times. Therefore, a swing of 40–42V peak (for a 2A3) is obtained with about .6V RMS at the input (= .8V peak), which is not bad, considering that the unbypassed cathode resistors produce a non-negligible amount of local feedback that improves the distortion level (measured below 0.6% at the stated output). Other useful additions (P1 and R8) allow a fine adjustment of the bias level of V1b to reduce the distortion as much as possible.

The linearity of this driver is excellent and practically flat from a few

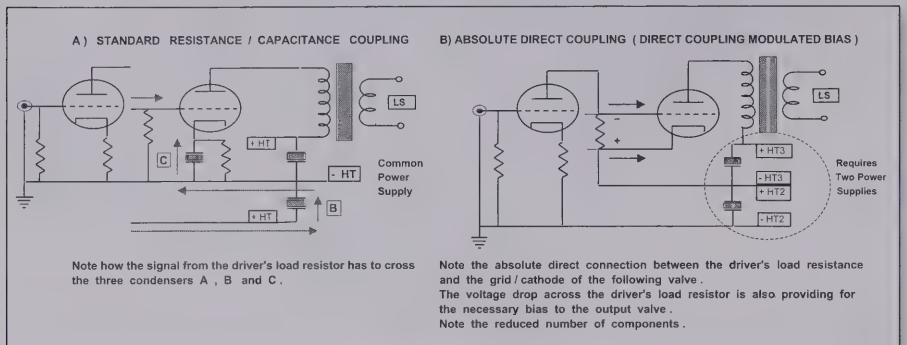

A) STANDARD RESISTANCE / CAPACITANCE COUPLING
B) ABSOLUTE DIRECT COUPLING (DIRECT COUPLING MODULATED BIAS)
LS
+ HT
C
- HT
Common Power Supply
B
+ HT
+ HT3
- HT3
+ HT2
- HT2
Requires Two Power Supplies
Note how the signal from the driver's load resistor has to cross the three condensers A , B and C .
Note the absolute direct connection between the driver's load resistance and the grid / cathode of the following valve .
The voltage drop across the driver's load resistor is also providing for the necessary bias to the output valve .
Note the reduced number of components .

FIGURE 1: Comparison between the classic resistance/capacitance coupling and the direct-coupling modulated-bias circuit (DCMB).

G-1957-1

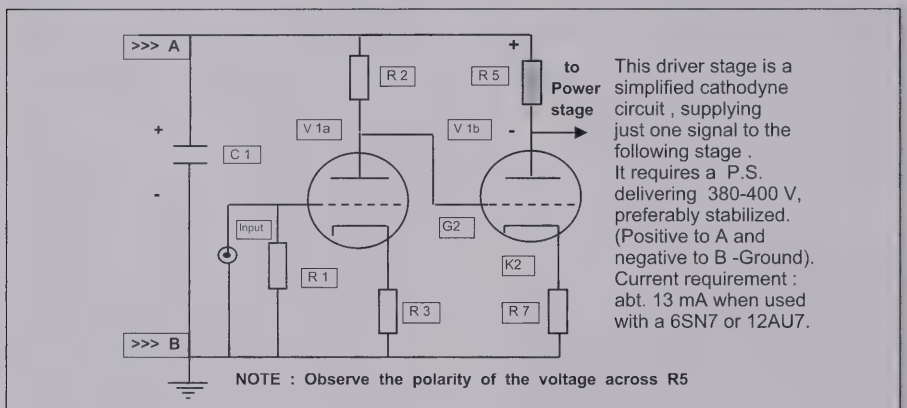

>>> A
>>> B
R 2
R 5
to Power stage
V 1a
V 1b
C 1
Input
G2
K2
R 1
R 3
R 7
This driver stage is a simplified cathodyne circuit , supplying just one signal to the following stage .
It requires a P.S. delivering 380-400 V, preferably stabilized. (Positive to A and negative to B -Ground).
Current requirement : abt. 13 mA when used with a 6SN7 or 12AU7.
NOTE : Observe the polarity of the voltage across R5

FIGURE 2: Direct-coupled driver stage.

G-1957-2

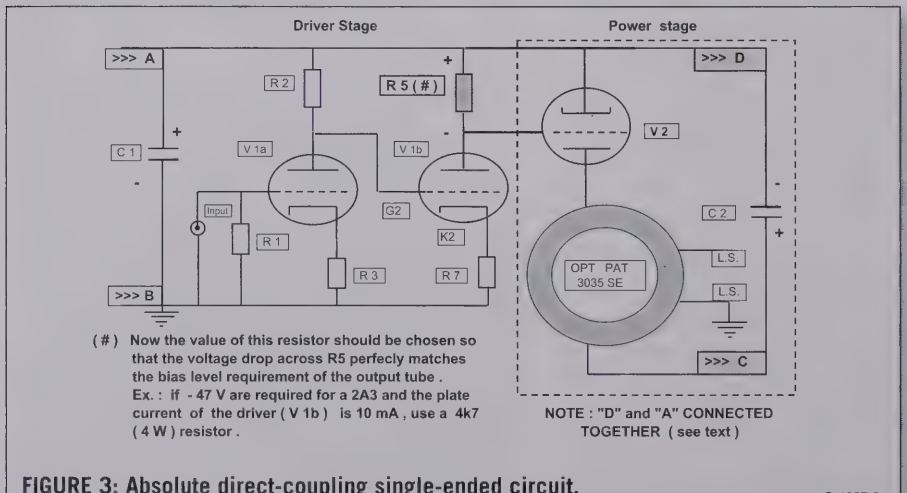

Driver Stage
Power stage
>>> A
>>> B
>>> C
>>> D
R 2
R 5 (#)
C 1
V 1a
V 1b
V 2
Input
G2
K2
R 1
R 3
R 7
C 2
L.S.
L.S.
OPT PAT 3035 SE
(#) Now the value of this resistor should be chosen so that the voltage drop across R5 perfecly matches the bias level requirement of the output tube .
Ex. : if - 47 V are required for a 2A3 and the plate current of the driver (V 1b) is 10 mA , use a 4k7 (4 W) resistor .
NOTE : "D" and "A" CONNECTED TOGETHER (see text)

FIGURE 3: Absolute direct-coupling single-ended circuit.

G-1957-3

Hertz to well above 100kHz! In fact, in a recent prototype of a driver with the same principles, using the 12AU7, the –3dB curvature came after 300kHz. Now consider using this layout for 2A3-type output tubes (*Photo 1*).

I mentioned before that an 8k2 load resistor would deliver bias in excess to the grid of V2. You could reduce the value of R5, but, again, this would considerably affect the gain of V1b. In fact, to get –46V bias for V2, you should use a 4k6 resistor.

But the DCMB configuration has still another ace: R10. This resistor connects the plate of V2 to the plate of V1b, through its 47–100kΩ path. You see that in the schematic's geometry, the current, coming from the driver-stage power supply, flows through R5 and then V1b and R7 downward (from positive terminal A to negative terminal B), whereas the current coming from the output tubes' power supply flows upward (from C through the OPT and then through R10 and R5 to terminal D).

Consequently, R5 is crossed by two currents having opposite directions, with the result that the voltage across its terminals drops, but by how much? The counter-current, Ic, is determined by the formula Ic(mA) = PDV2/(R10 + R5), where PDV2 is the potential difference between the plate of V2 and terminal D, in volts, and R10 and R5 are expressed in kΩ. The voltage reduction Vd will then be Vd = Ic × R5.

COUNTER CURRENT

To simplify the text that follows, the current flowing through R10 is called the counter-current. For example, if PDV2 is 270V (grid at about –42V), R10 = 50k, and R5 = 8.2k, the counter-current would be about 4.6mA. Supposing that the plate current of V1b is 10mA, the voltage across R5 would drop from 82V to 44V. {(10 – 4.6) × 8.2k = 44.28V}. But when V2's grid is driven less negative by the driver (say to –2V, instead of –42), PDV2 drops to approximately 100V, and the counter-current to 1.72mA.

If you are sufficiently skilled, you can calculate the corresponding amount of negative feedback. Nothing prevents you from making R10 adjustable, for instance, by shunting R10 to a higher value, using a potentiometer in series with a limiting resistor. You can then fine-tune the bias of V2 (necessary for a push-pull layout, *Photo 2*).

Moreover, nothing prevents you from connecting R10 to terminal C, instead of the plate of V2. But you will lose some nice local negative feedback that keeps distortion low in this final loop (OPT–power tube–driver).

The current supplied through R10 should not be too high, or it could completely cancel the amount of plate current supplied to R5 via V1a, thus driving the grid of V2 positive. Better stick to the high values mentioned in the schematic, which are tested and approved. I have inserted R11 to avoid parasitic oscillations. The values stated are not binding.

With the Plitron OPT PAT 3035 the results were excellent for a SE amplifi-

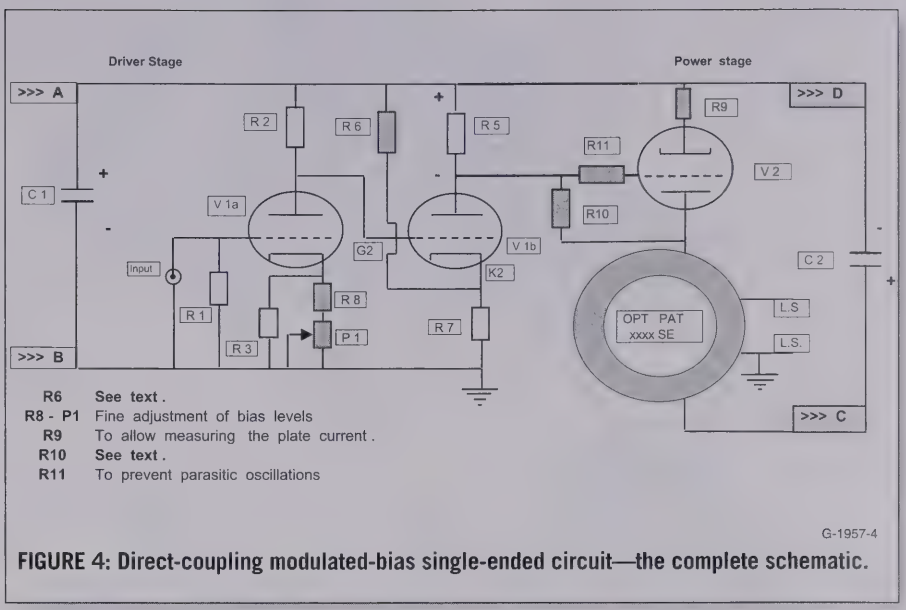


FIGURE 4: Direct-coupling modulated-bias single-ended circuit—the complete schematic.

Power Watts	% THD
1	0.50
3	0.60
5	1.00
7	2.50
7.5	5.00
8	7.00
10	12.00

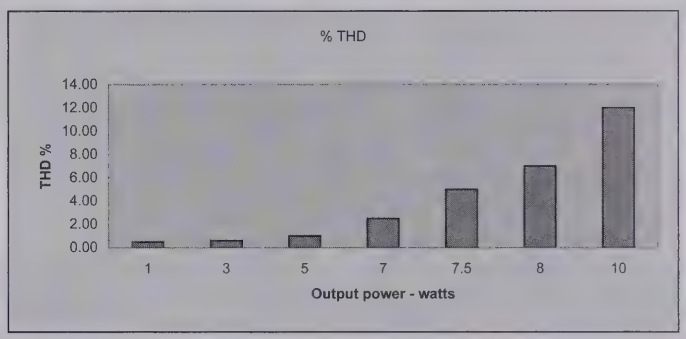


FIGURE 5A: THD% versus output power (watts). G-1957-5a

Frequency	-dB
5Hz	3.10
10Hz	0.92
20Hz	0.35
40Hz	0.09
100Hz	0.00
200Hz	0.00
500Hz	0.00
1k	0.00
2k	0.00
5k	0.09
10k	0.54
20k	1.31
30k	2.16
40k	2.85
50k	3.74
60k	4.44

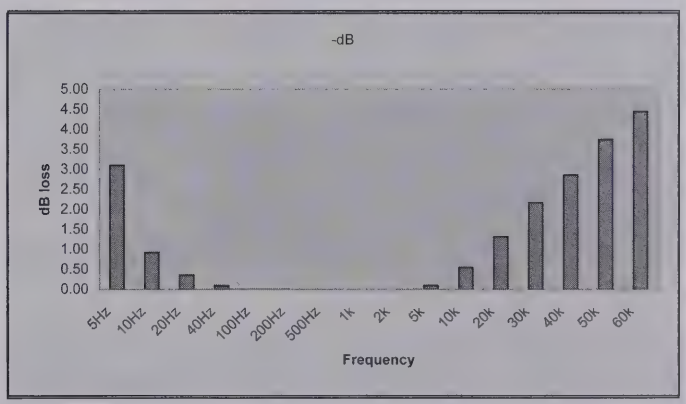


FIGURE 5B: dB loss over the frequency range. G-1957-5b

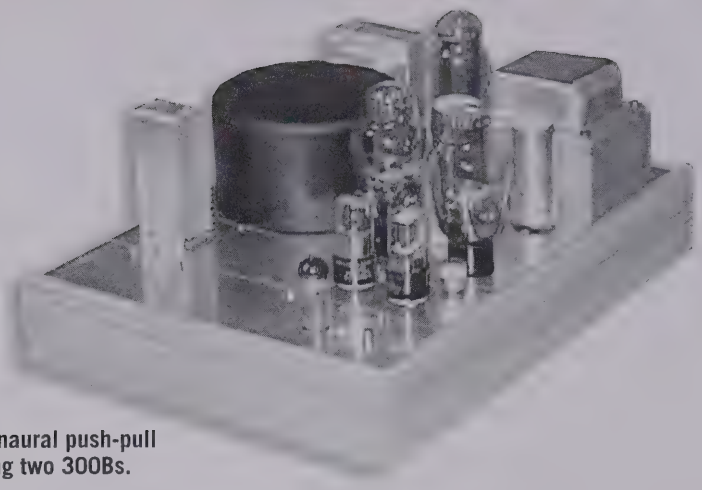


PHOTO 2: Monaural push-pull amplifier using two 300Bs.

er. I followed the SE with a push-pull amplifier using a phase inverter (the ARIPS circuit published in *Glass Audio* 1/00), with drivers of the topology described here. It uses another Plitron OPT, style 4070-CFB (see *Photos 1* and *2* for the complete amplifiers).

The results (*Figs. 5a* and *5b*) are outstanding. I will supply data and schematics on request. Just send your comments and queries to ari.polisois@wanadoo.fr and I'll do my best to respond. ❖

Glass Shard

Elegant Racks for Electronics

While speaker builders have come up with one excellent product after another, valve builders keep on reaching for the same old chassis, if not for an inverted cake tin. They seem to have missed the general line of set-design and construction of the past hundred years. The result is an ugly, cumbersome, unserviceable, and often dangerous box of tricks. Would you want such a monster in your sitting room after one of the kids burned a hand or suffered a boot from it?

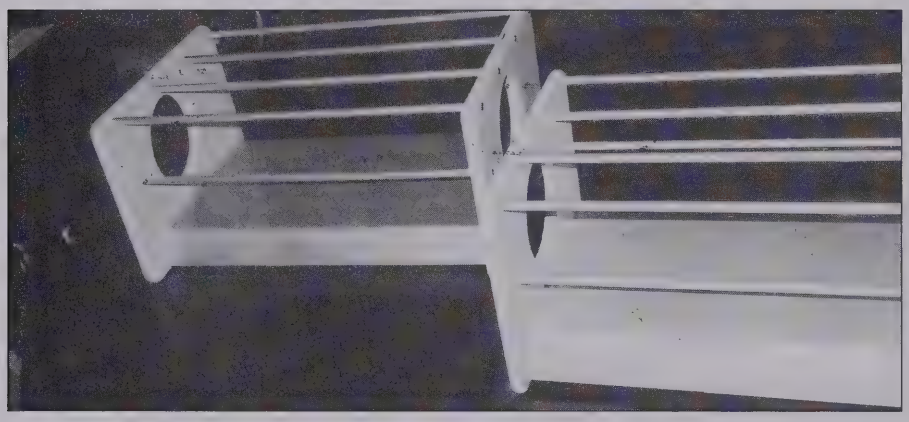


PHOTO 1: Panyrack enclosures.

PHOTO 2: 40 × 26 × 20cm Panyrack with bottom plate, panels (with 10cm diameter opening), chassis, tubes and cotton-wound 4mm threads, and lockplate screws. (brass)

It is time for a change. Years ago I worked out a handy enclosure for a better construction. It's safe, strong, serviceable, and quite handsome. It requires no special materials, and any valve builder can adjust it to whatever size he/she likes in a variety of designs and colors. I call it a Panyrack.

Overall size of the rack I use (*Photo 1*) is 40.6 × 26 × 20cm (l × w × h). The materials (*Photo 2*) include

2—panels, 18mm MDF, 26 × 20cm
8—4mm treads, 39cm long
6—8mm anodized aluminum tubes, 38cm
2mm anodized aluminum chassis, 38 × 22cm, plus 4cm back at right angles and another 4cm front at 70° slant
16—4mm lockplate screws
Some cotton wool and 80cm 4mm spaghetti
38 × 24cm 1mm perforated anodized bottom plate, 4 feet
Total cost less than $50

Mike Panymo
Eindhoven
The Netherlands

More Power for the SE Triode Amp

Here's an upgrade to a previously published amp design that promises more bang for the buck. **By John L. Stewart**

PHOTO 1: Completed SE amp.

While working on the earlier affordable SE amp (*GA* 4/00, p. 1), it occurred to me there might be an easy way to get even more power with only a slight increase in cost (*Photo 1*).

All single-ended amplifiers need to run in Class-A mode if they are to deliver good quality sound. In order to do that, they need to be capable of dissipating considerable heat. Tubes in the list for the original low-cost SE amp barely fit that requirement.

However, several compactrons with a beam tetrode and high mu triode in a single envelope are available on the NOS market at reasonable cost (*Table 1*). They have power-handling ability that is about 50% better than those on the previous list. To further this project, I selected the 6LU8.

CIRCUIT FEATURES

1) Operation in triode or ultralinear mode.
2) Operation with or without feedback.
3) Power frequency hum cancellation.
4) Start/standby and run modes.
5) Excellent performance.
6) Maintenance of low cost.

TRIODE OR ULTRALINEAR?

The original amplifier used a low-cost Hammond 125E for its output transformer, which has a center tap that could be connected to the screen of the beam tetrode, thus providing a degree of ultralinear operation. I arranged layout of the various parts so that a comparison of performance could be made between triode and ultralinear topologies. Referring to *Fig. 1*, see that the screen grid of the beam tetrode is shown unhooked. You can make a connection either directly to the plate (triode operation) or to the 125E center tap (ultralinear).

CAUTION: Don't use a switch to make the circuit change. Energy stored in the magnetic field of the 125E tries to keep current flowing. You could cause a failure of the insulation in the transformer because of the large induced voltage caused by switching. When you make the change, you should completely disconnect your amplifier from the power source. [Wait for the power supply capacitors to discharge before changing connections—Ed.]

At midband the resulting amplifier delivered 5W in triode mode and 6W when connected for ultralinear operation. Refer to *Table 2* for a summary of performance of the various configurations.

THE MODIFIED AMPLIFIER

As shown in the schematic, the amplifier is connected so that all of the gain is used by feedback. If you would like to run without feedback, then unhook R4 from terminal one of the 125E and con-

TABLE 1
SUMMARY OF POWER TETRODES ACCOMPANIED BY A TRIODE VOLTAGE AMPLIFIER

TYPE		TETRODE		TRIODE			BASE CONNECTION	
		WATTS	VOLTS	WATTS	VOLTS	μ		
6HZ8	Plate	8	330	1.0	330	70	NEO	9DX
	G2	2	330					
6KY8,	Plate	12	300	1.5	330	64	NOVAR	9QT
15	G2	1.9	150					
6LR8,	Plate	14	400	2.5	400	58	NOVAR	9QT
21, 31	G2	2.75	300					
6LU8,	Plate	14	400	2.5	400	58	COMP	12DZ
16, 21	G2	2.75	300					
6MF8,	Plate	12	400	2.5	400	58	COMP	12DZ
15	G2	2.75	300					
6MY8	Plate	16	400	2.5	400	58	COMP	12DZ
	G2	2.75	300					

nect to common. You will also need to remove C3 and R5 from the circuit and connect C2 to the junction of R6 and R7.

The coupling cap between the voltage amp and the power amp becomes more critical as more feedback is used. You are normally told to use as large a coupling cap as practical at this position. However, as feedback is increased, a hump will appear in the low-frequency response.

I measured up to 4dB rise at 30 to 40Hz. C3 and R5 provide a step in the low-frequency response. This allows more feedback to be used without instability.

An important addition to this amp are three grid-stopper resistors. This tube has very high transconductance and will likely oscillate on its own if given a chance. I knew I had problems when my FM receiver was interfered with while the amplifier was running. I observed spectrum up to 150MHz. Grid-stopper resistors lower the Q (quality factor) of the circuit according to the formula

$$Q = (1/R) \times SQR (L/R)$$

As little as 100Ω in a conductor interferes with the RF to the extent that it is eliminated. The audio is left intact.

The remaining LF time constant in this amplifier is the filter section of the power supply. Many experimenters either ignore this one or simply follow the lead of others. However, it is in the audio path and does have considerable effect on the final result.

For triode operation connect an 8Ω loudspeaker to terminals 2 and 6 of the 125E. If you would like to use the ultralinear mode, then you can connect an 8Ω loudspeaker to terminals 3 and 6.

TABLE 2
SUMMARY OF PERFORMANCE MEASURED AT 1KHZ

ULTRALINEAR WITH FEEDBACK	WATTS	1	2	3	4	5	6
Harmonic Distortion %	2nd	0.28	0.44	0.45	0.53	0.74	1.18
	3rd	0.16	–	–	0.35	0.36	0.96
		Damping Factor = 17					
Ultralinear Without Feedback	Watts	1	2	3	4	5	6
Harmonic Distortion %	2nd	2.71	3.93	5.09	6.65	7.71	7.62
	3rd	0.70	0.80	1.10	1.20	1.43	4.05
		Damping Factor = 2.3					
Triode With Feedback	Watts	1	2	3	4	5	
Harmonic Distortion %	2nd	0.71	1.04	1.30	1.66	1.98	
	3rd	0.22	0.25	0.49	0.50	0.79	
		Damping Factor = 15					
Triode Without Feedback	Watts	1	2	3	4	5	
Harmonic Distortion %	2nd	3.95	5.83	7.11	8.93	8.83	
	3rd	–	0.23	0.21	0.20	2.07	
		Damping Factor = 2.4					

THE POWER SUPPLY

You will need more power for this version of the SE amp. Here it is supplied by a Hammond 271X transformer. Filtering is provided by a PI section consisting of a Hammond 156L, 5H choke, and a pair of 100µF caps. This time the caps are rated at 450V working (*Fig. 2*).

The filter section is resonant at 10Hz. That has an effect on the low-frequency performance of the amp. A simple regulated power supply would eliminate this problem. Perhaps next time.

A current sampling resistor of 10Ω is in the center tap lead of the HV winding. Using a 10× probe, I measured peak current of 250mA on the scope. Average current was 70mA.

The pilot light has been moved to the 5V winding to somewhat relieve the load on the 6.3V winding. However, total load is well within the capabilities of the 271X. I measured input to the power transformer to be 46VA in the run mode. In standby it was 20VA. The 271X is rated for 63VA input.

A start/standby mode is provided by the 3PDT, center off switch S1 sections

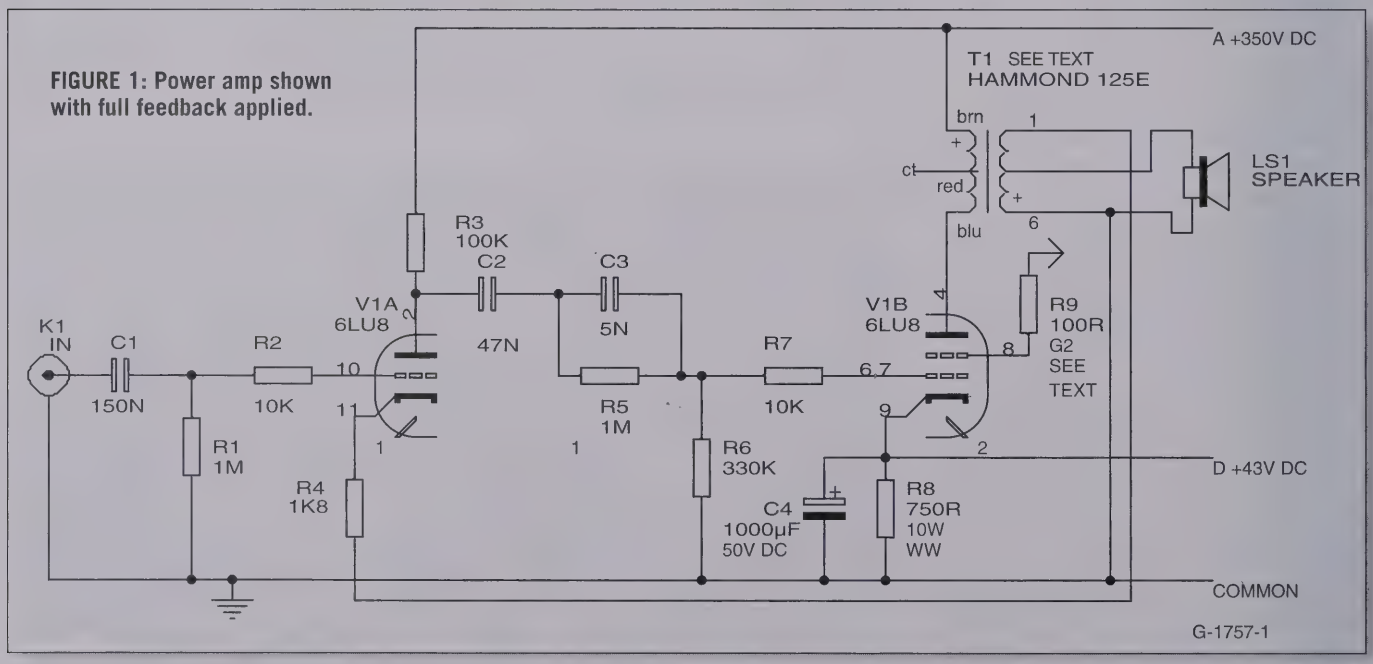


FIGURE 1: Power amp shown with full feedback applied.

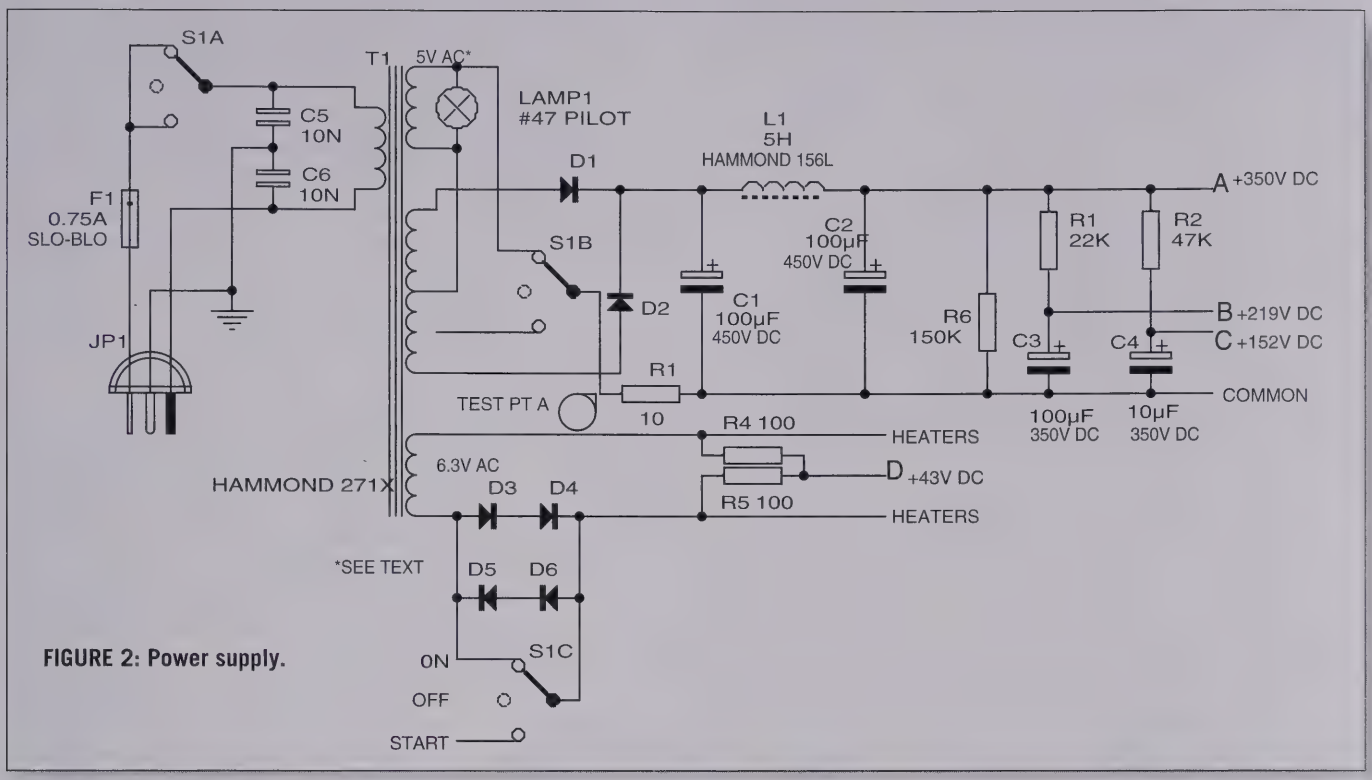


FIGURE 2: Power supply.

A, B, and C. Diode ring D3 through D6 sets the heaters to about 4.9V when S1C is open. C5 and C6 have Mallory part number UN103M. These caps are Underwriters-Laboratory-approved for across-the-line applications.

POWER FREQUENCY RIPPLE CANCELLING

In a previous article (*GA* 3/98), I described a simple addition to the power supply circuit which would almost eliminate the power frequency hum component. That would be 60Hz in North America and 50Hz in Europe and elsewhere. This component of hum often results when a center-tapped transformer is used in the power supply. Two halves of the HV winding may not be balanced for resistance. For example, in the Hammond 271X the two sides of the HV winding measured 167 and 142Ω.

The power frequency ripple happens to be in the same range as the resonance(s) of most loudspeaker systems. This sometimes causes problems in systems using SE triode amps. Here is a practical application of that circuit.

You will find the fix in this amplifier easy to make. The 5V winding is connected in series with the center tap of the HV winding. The extra 5V will be series aiding for one side of the HV winding and series opposing for the other side. There are no polarity markings on most power transformer leads. On the first try there is an even chance the hum will become worse.

Your best check for the proper connection is to use an oscilloscope. Connect the scope probe to the ungrounded end of the 10Ω resistor (TP A) in the center tap return lead. Proper connection of the 5V winding results in the current pulses all having about equal amplitude. If you have connected the 5V leads the wrong way, alternate current pulses will have somewhat different heights (*Fig. 3*).

TABLE 3

COMPARISON OF PERFORMANCE MEASURED AT 100HZ. 125SE VERSUS 1628SE. DISTORTION AT 1W.

OUTPUT TRANSFORMER		125SE	1627SE
A) Ultralinear Without Feedback			
Harmonic Distortion %	2nd	15.3	2.9
	3rd	3.1	0.4
B) Triode Without Feedback			
Harmonic Distortion %	2nd	12.2	2.8
	3rd	1.5	

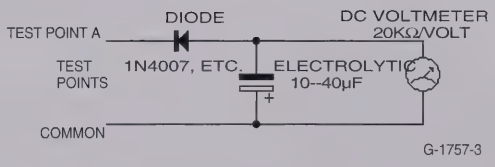


FIGURE 3: Ripple cancelling test circuit.

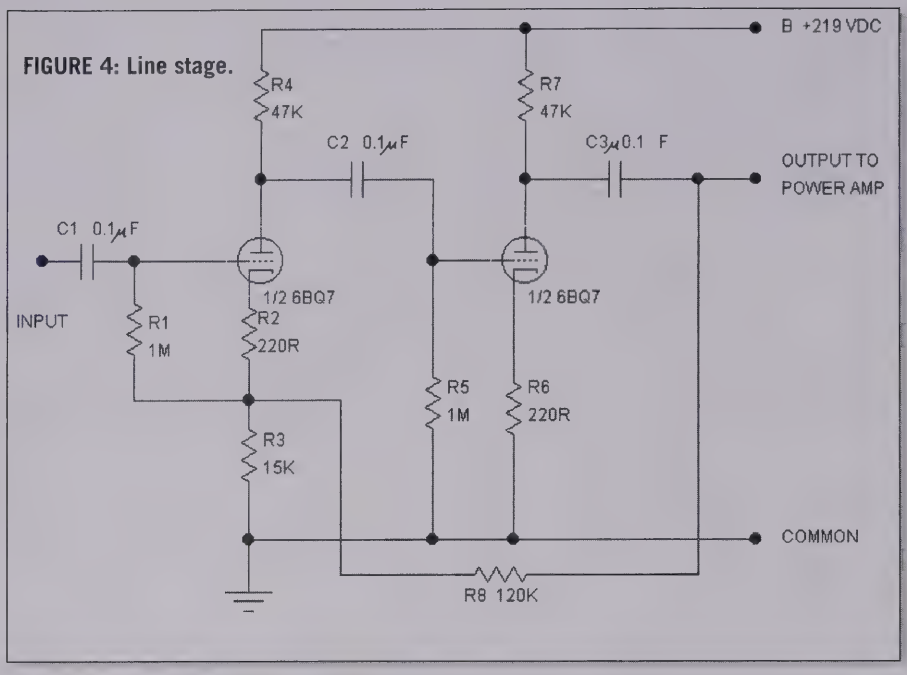


FIGURE 4: Line stage.

TABLE 4
PARTS LIST

POWER AMPLIFIER

R1, R5	1M
R2, R7	10k
R3	100k
R4	1k8
R6	330k
R8	750R 10W, WW
R9	100R
C1	0.15μF SBE Orange Drop
C2	0.047μF
C3	0.005μF
C4	1000μF Mallory
T1	Hammond 125E
V	6LU8

POWER SUPPLY

R1	22k
R2	47k
R3	10R
R4, R5	100R
R6	150k
D1–D6	1N4007
L1	Hammond 156L, 5H
S1A, B, C	Switch, 3PDT, center off, mode 41-252-0
C1, C2	100μF, 450V DC Antique C-ET100-450
C3	100μF, 350V DC Antique C-ET100-350
C4	10μF, 350V DC Antique C-ET10-350
C5, C6	0.01μF Mallory UN103M
Pilot	#47
T	Hammond 271X

LINE STAGE

R1, R5	1M
R2, R6	220R
R3	15k
R4, R7	47k
R8	120k
C1	0.1μF SBE Orange Drop
C2, C3	0.1μF
V	6BQ7

All resistors are ½W unless otherwise noted.
Orange Drop Caps are 600V.
Most parts are available from Antique Electronic Supply, 6221 South Maple Ave., Tempe, AZ 85283.

After I made the proper connection, I measured a 12dB reduction of the power frequency ripple as compared to the normal hookup...and it cost nothing.

If you don't have an oscilloscope to make this adjustment, two other kinds of measurements are possible. You could use a peak responding AC voltmeter such as the HP 410A, 410B, or 410C to measure the voltage peaks produced across the current sampling resistor. Correct connection of the 5V winding leads is that which produces the smallest voltage. This will vary depending on your circuit but will be in the range of 2.5V.

Finally, you can build your own simple peak responding voltmeter (*Fig. 3*). Most any signal or power diode will work. From my junk box I tried a 1N4007 as well as a very old 1N56A, which is a germanium device with a smaller forward drop. This worked best.

The external VOM of 20,000Ω per volt was set to the 3V range. Connect the 5V winding leads to give the lowest reading when connected to the test point on the 10Ω sampling resistor. Indication will be about 2.5V.

LINE STAGE

When you use the feedback version of the amplifier, you will find the gain to be somewhat low. In order to get enough gain, most experimenters will try three stages of gain. Instability often results when feedback is connected. Even the famous Williamson amplifier exhibits some low-frequency problems, since there is too much gain and phase shift inside the feedback circuit.

A simple line stage (*Fig. 4*) can easily fix this problem. This is an application in which a pair of feedback amps is connected to provide enough gain without instability. As shown, the line stage has a gain of eight.

CONCLUSION

Was the project worth the time and effort required? I would say yes. For a very reasonable cost, you can gain some experience of what vacuum tube audio is really about.

In my various designs I try for synergy; that is to say, the various parts should somehow complement each other so that the final result will be easy to implement, safe, and have a reasonable cost. All designs will have some trade-offs. The designer's job is to separate those that are important from the rest.

The primary objective I had in mind with the affordable SE amp was to illustrate what is possible on a tight budget. I wanted to avoid exotic and otherwise expensive components which seem to be running rampant in the present vacuum tube audio revival.

For those who would care to spend a little more money, the most effective improvement you can make to this design is a better output transformer. The Hammond 125E was not designed with high fidelity in mind. I recommend the Hammond 1628SE.

Available output power will increase since losses in the 1628SE are less. You will get a large improvement in the low-frequency response. Distortion at all levels would be reduced since the 1628SE is specially designed for single-ended applications. Refer to *Table 3* for some comparative distortion measurements made at 100Hz. ❖

EQUIPMENT USED
HP 200CD Oscillator
HP 302A Wave Analyzer
GW GAG-810 Oscillator
Rohde & Schwarz BOL 4 Trace 100MHz Scope
RS 22-168A DMM
Sanwa AX 303-TR Analog Multimeter
PicoScope ADC-100 Virtual Instrument
Electronic Workbench Software

Glass Shard

Safe Bias and Balance Measurement

Several circuits have been proposed to set the biasing and balance of push-pull amplifier circuits. Many are inconvenient and, in some instances, are downright dangerous. The user is often required to make measurements where high potentials are found.

The DC balance setting may depend on the output transformer having equal resistance in both halves of its primary. Some lower-cost transformers, such as the Hammond 125 series, older PA, and hi-fi often have unequal resistance in the two halves of their primary. For example, the Hammond 125E measured 78 and 84Ω.

To get around these difficulties, you need a different approach. The circuit described here (*Fig. 1*) avoids these problems. All of the metering is done in the cathode circuit at low voltage. I had originally used this circuit to meter each of the two ultralinear amplifiers I had built around 1960. I still have them in working order.

First of all, I wanted a way to measure the total cathode current both at idle and under signal conditions. A value of 200mA full scale would do this well. The other requirement was to set DC balance.

In *Fig. 1* the measurement circuit consists of the resistors R5, R6, R9, R10, the DPDT switch S1A, B, and the 1mA meter. The switch is preferably push button and is shown in the normal position. A toggle or slide switch would work as well. For this example the output tubes are triode-connected 6L6GCs.

While the switch is in the normal position, the cathodes are tied together. The parallel combination of R5 and R6 will be 10Ω. Cathode current of 200mA will produce a 2V drop across a 10Ω resistance.

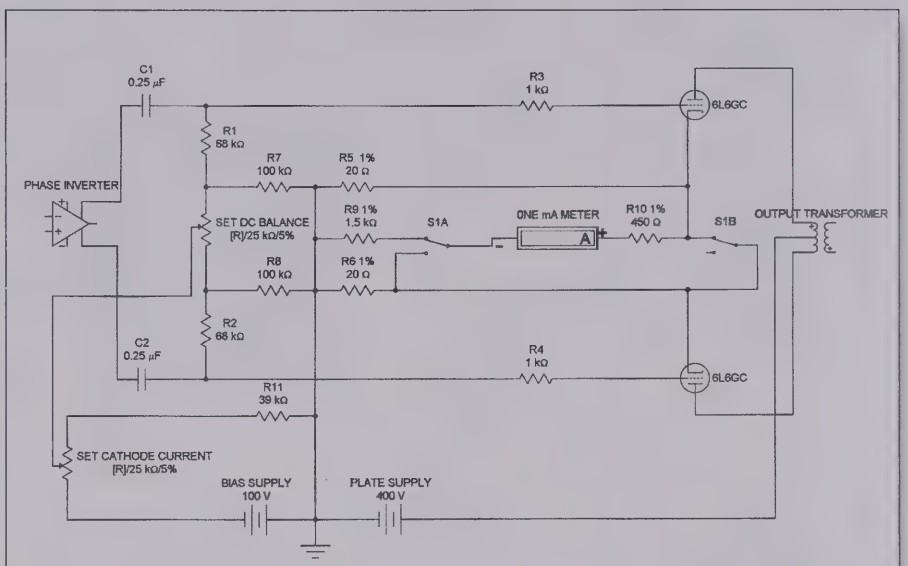


FIGURE 1: Bias and balance circuit for a push-pull amplifier.

G-1729-1

The indicator is a 1mA analog meter, which works out to 1000Ω per volt for voltage measurement. The meters I used have an internal resistance of 50Ω. In order to get a full scale of 2V, another 1950Ω is required in series with the meter. That is provided here by resistors R9 and 10. Bias is set by the cathode-current adjustment potentiometer.

Pressing the push-button switch S1 connects the metering circuit between the cathodes of the power stage. The DC balance potentiometer is adjusted until zero voltage is indicated across the 20Ω resistors R5 and 6. The balance measurement is not dependent on resistance of the two halves of the output transformer primary.

Some may question the shunt loading effect the 2000Ω measurement circuit has on the overall accuracy. It works out to an error of 1%, which is well inside the accuracy expected of an analog meter.

Another concern may be the effect of leaving the 10Ω in the cathode circuit during operation. I recall that some later Dyna amplifiers used a small resistance in the adjustment of the bias. The resulting voltage drop was 1.56, which was used as a comparison to a fresh zinc carbon cell. That is how they established the operating point for the output section. They had also taken the time to show that including this small resistance improved their distortion readings.

Perhaps someone else has a better recollection of that circuit than I do. The phase inverter chosen will depend upon your preference. ❖

John Stewart
King City, ON
Canada

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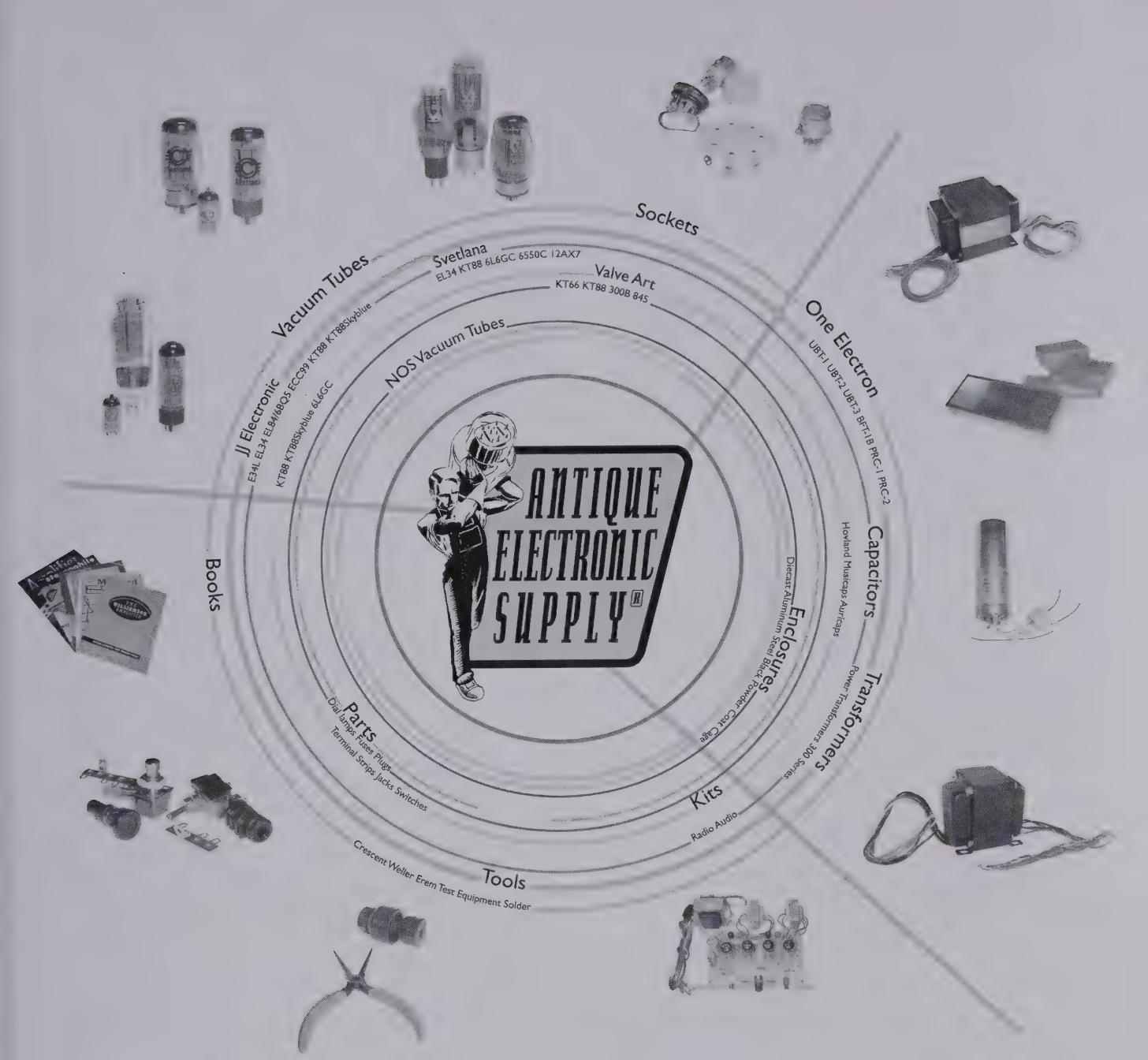

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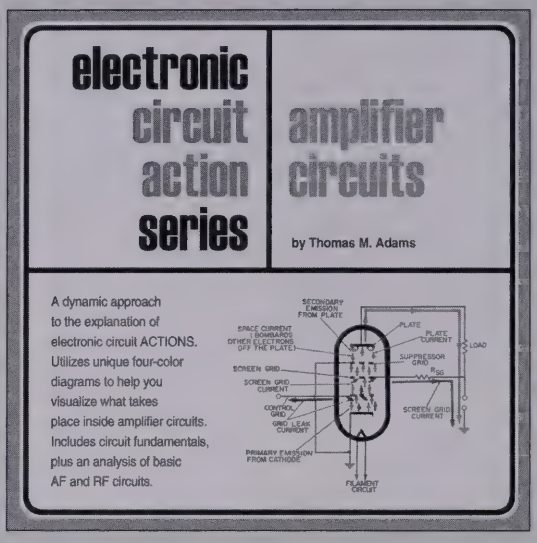
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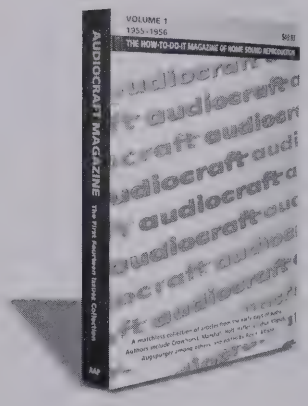

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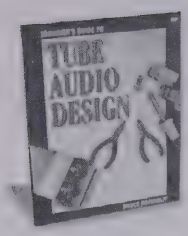

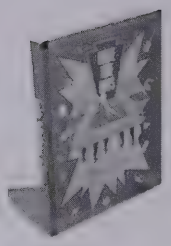
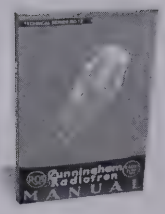
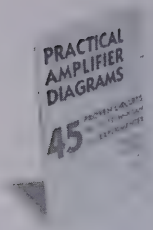

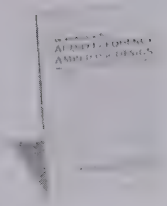

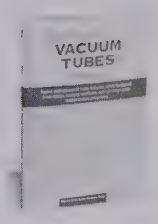

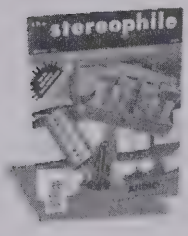

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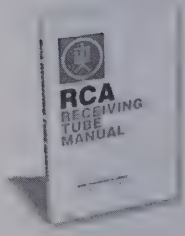

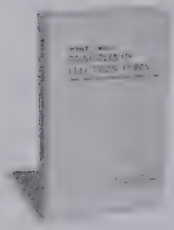
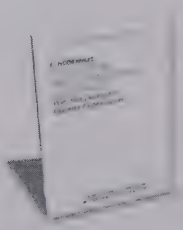
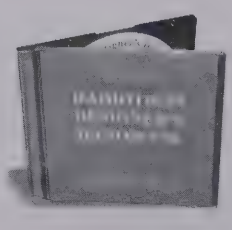
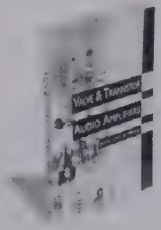

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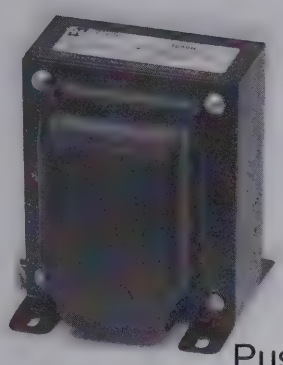

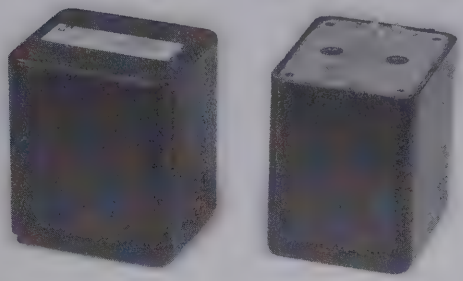

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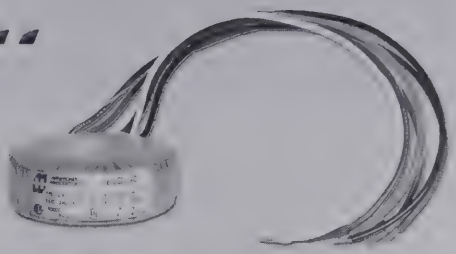

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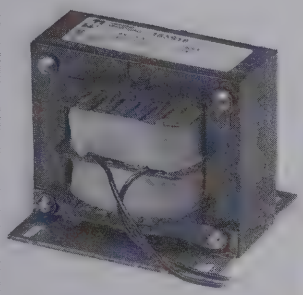

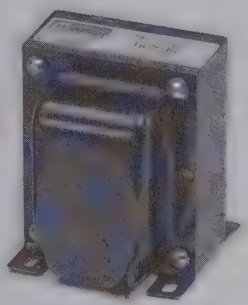

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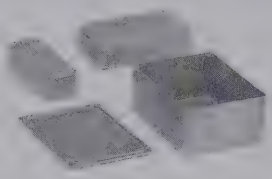

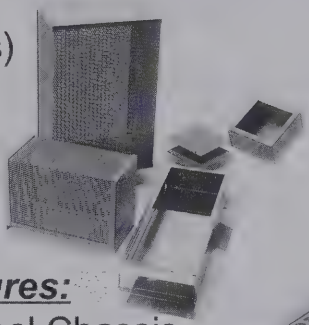

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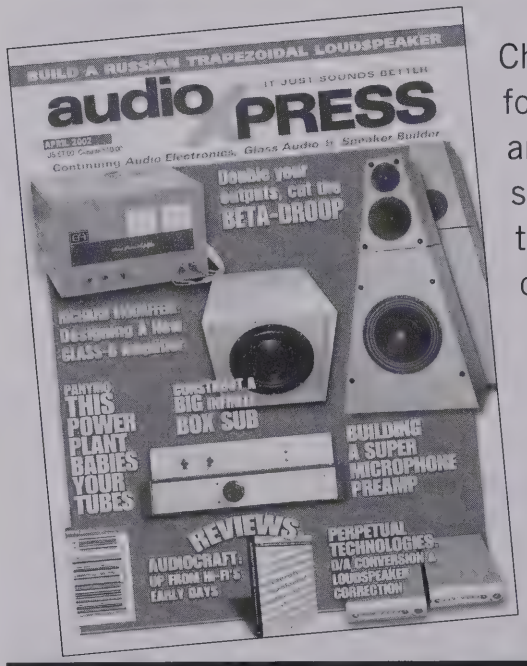
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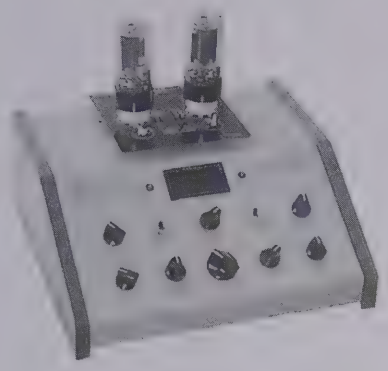

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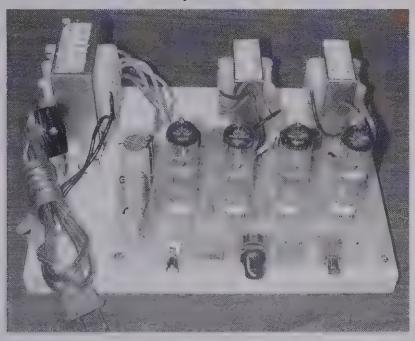

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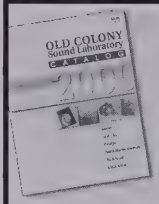

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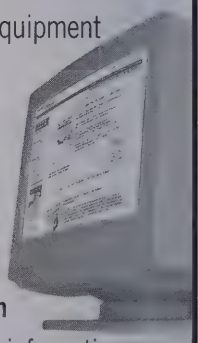

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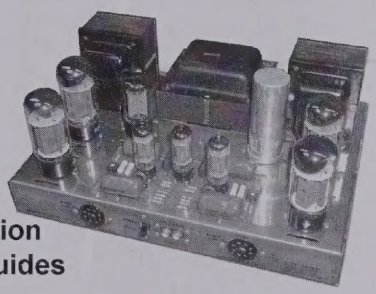

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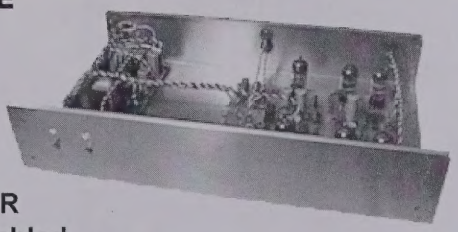

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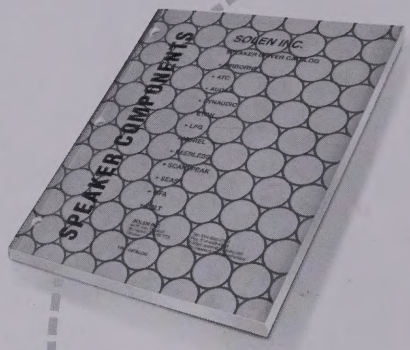

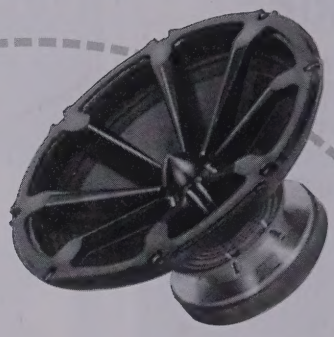

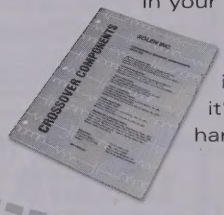

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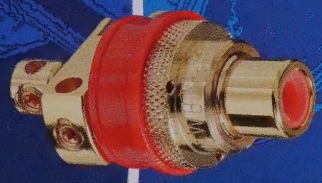
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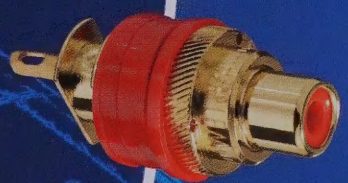
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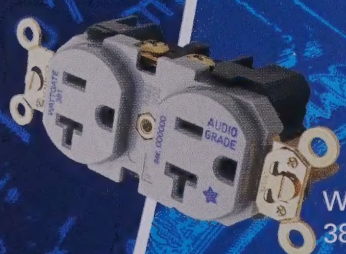

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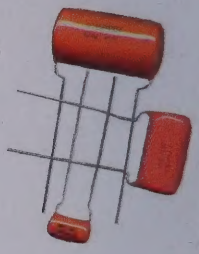

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